Illuminating Engineering

TRANSACTIONS

OF THE

ILLUMINATING ENGINEERING SOCIETY

VOL VI.

JANUARY-DECEMBER

1911

Subject Index and Index to Authors

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SUBJECT INDEX

INDEX TO AUTHORS

The letter C indicates contribution; the letter D indicates discussion.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VI. JANUARY, 1911. NO. 1

MINUTES OF COUNCIL MEETING.

JANUARY 12, 1911.

At the meeting of the council held January 12th, in the general office, a statement of the society's membership and finances as of December 31, 1910, elicited that the membership totaled 1,530; secondly, the earnings for the year had fallen short of the expenses. However, a comparison of the assets and liabilities showed that the gross surplus which had been accumulated amounted to $2,873.46.

Commenting upon the society's financial condition Mr. L. B. Marks, chairman of the finance committee, said that his committee was of the opinion that stricter economy in expenses should be observed. Unless this were done, he emphasized, the surplus accumulated might be seriously impaired. There was nothing particularly discomforting in the report of the finances, he added, other than that a curtailment of expenses seemed necessary if the ordinary current revenue were to be depended upon.

A draft of the annual report of the council to be submitted to the Society at the annual meeting was presented by the secretary.

As chairman of the lecture committee President E. P. Hyde reported that he had been unable to prepare a final report because certain matters pertaining to the committee were still in abeyance. Until these were disposed of such report he said would not be submitted. He presented instead a progress report. In the latter it was stated that 240 tickets of admission to the course had been sold. Whether a supplementary or final report would be submitted was dependent upon the reappointment of the committee by the new administration to continue the work.

Thirteen applicants were elected members. Eighteen resignations were accepted.

In view of the approaching retirement from office of President Hyde the following resolution was unanimously adopted:

That the council extend to President Hyde an acknowledgment of the distinguished services rendered by him during his encumbency and that a sincere vote of thanks be tendered him for his achievements in promoting the objects and welfare of the Society.

Certain communications referring to relations of the Society with its foreign members were held for subsequent attention.

Those present at the meeting were: President E. P. Hyde; W. Cullen Morris, treasurer; Dr. A. S. McAllister, Mr. Bassett Jones, Jr., Mr. L. B. Marks, Mr. V. R. Lansingh and Mr. Preston S. Millar, general secretary.

ANNUAL MEETING.

The fifth annual meeting of the Society was held Friday evening, January 13th, at the Machinery Club in New York City. Forty members were present. The meeting was preceded by an informal dinner.

President Hyde called the meeting to order, addressing the members briefly. Referring to the record of the Society since its inception, he commented upon the remarkable growth which has been experienced—a growth so marked as to suggest that the Society has nearly attained maturity. This growth has not been in numbers alone, because the Society has attained a status of much influence and has assisted the science and art of illuminating engineering in gaining a measure of the recognition which is its due. To promote further development the Society needs the encouragement and coöperation of those who are qualified to be of assistance in this way. President Hyde then introduced Mr. W. W. Freeman, of the National Electric Light Association, and former chairman of the New York Section of the Illuminating Engineering Society, as one from whom encour-

agement and coöperation had been received in the past and from whom it was expected in the future.

Mr. Freeman called attention to the rapid increase in the number of technical societies being organized for one purpose or another. Whether they could all survive he expressed some doubt. But those which had justified their existence are looked upon by commercial organizations with favor. And where a society like the Illuminating Engineering Society has by its work merited coöperation, their coöperation will be forthcoming.

Mr. L. B. Marks, the Society's first president, reviewed the early progress of the Society and discussed the scope of the influence of illuminating engineering. He intimated that there has been and is to a certain extent some misapprehension as to the significance of the term illuminating engineering. Indefinite as may be the province of illuminating engineering it is nevertheless a distinct entity. It has been called a "specialization" which perhaps approaches the admission that it is a science. That it is in a large measure a collocation or correlation of the fundamental laws and principles of other phases of scientific study is beyond cavil. The misconception of illuminating engineering can be ascribed to a lack of knowledge as to what illuminating engineering really is.

Mr. Marks continued that there has been a marked interest manifested in illuminating engineering by men who are prominent in the provinces of art and science. This auspicious interest may be attributed to the work of the Society as indicated in its Transactions and, as might be expected, to the recent lecture course in illuminating engineering at Johns Hopkins University, which, in his opinion, was the most distinguished work ever uudertaken by the Society. As a concrete example of the protracted interest in illuminating engineering and the broad scope of the science, Mr. Marks cited the fact that scientists in different parts of the country are now devoting considerable study to illumination as a means to augment solutions of the difficulties encountered in the congested sections of cities, particularly in the tenement districts.

Dr. C. H. Sharp, who succeeded Mr. Marks to the Society's presidency four years since, called attention to the fact that the

inception of the Society came at a time when unprecedented attention was being devoted to the development and perfection of several of the newer illuminants which are so widely used today. One of them, the tungsten lamp, was unknown as far as the public was concerned; and one or two of the others has been in use only a short time. Even flaming arc lamps were still in the experimental stage. The formation of a society to encourage the study of the science and art of illumination was timely and its gratifying development has undoubtedly been aided by the advent of these higher efficiency illuminants.

Dr. Sharp referred to the second year of the Society's history during which time the probability of the ultimate success of the Society was put to a severe test by the failure of the first enthusiasm which had characterized its organization, and told of the gratification of all those interested in the successful record which had been made, and which included the first technical convention at which was set the high standard which has been met by all subsequent conventions of the Society.

The report of the Council to the Society was read by General Secretary, P. S. Millar. The report, which will appear in the February issue of the Transactions, reviewed the affairs of the Society during the past year. The most notable of these were the increase in membership of approximately fifty per cent. and the success achieved by the course of lectures on illuminating engineering at Johns Hopkins University.

Mr. W. Cullen Morris, treasurer, presented an oral report of the financial condition of the Society. This was supplemented by a report presented by Mr. L. B. Marks, chairman of the finance committee. Mr. Marks said that a slight deficit had been incurred during the previous year. This was accounted for by a large increase in the cost of publishing the Transactions, together with several extraordinary expenses which were not strictly chargeable to the past year. In analyzing the items of expense Mr. Marks pointed out that less than 70 per cent. of the running expenses came from dues. Comparing the income from dues with the cost of the Transactions, it was shown that only about 47 per cent. of the net income was applied toward general expenses. The difference, 53 per cent., represented the expenditure for Transactions alone.

ELECTION OF OFFICERS.

President Hyde called for the report of the committee of tellers, which committee had counted the votes of the members in the annual election of officers and in connection with the vote on constitutional revision. The report certified to the election of the following officers:

President, Dr. A. E. Kennelly.

Vice-President, representing Chicago Section, Dr. Herbert E. Ives.

Vice-President, representing Philadelphia Section, Mr. James T. Maxwell.

Vice-President, representing New England Section, Mr. Theodore Piser.

Directors, Mr. J. C. D. Clark; Mr. F. N. Morton; Mr. Arthur Williams.

General Secretary, Mr. Preston S. Millar.

Treasurer, Mr. V. R. Lansingh.

The committee reported also an affirmative vote on the constitutional amendment extending the terms of office of all committees until February.

In the absence of Dr. Kennelly, retiring-President Hyde relinquished the chair to Mr. Lansingh, senior Vice-President of the Society, who adjourned the meeting.

SECTION MEETINGS.

CHICAGO SECTION.

The Chicago Section held a meeting on the evening of January 13th, in the Coliseum in connection with the sixth annual Chicago Electrical Show and at the invitation of the Electrical Trades Exposition Company and of the Coliseum Company. The meeting proper was preceded by a dinner in the Coliseum Restaurant at 6:30 o'clock at which about 40 members and guests were present. At its conclusion the party proceeded to the

assembly hall on the second floor of the Coliseum Annex where Chairman F. J. Pearson called the meeting to order. The subject for discussion was the paper on "Luminous Efficiency" that was presented by Dr. H. E. Ives before the Philadelphia Section in January, 1910. A. L. Eustice gave an abstract of the paper and opened the discussion. Others who participated in the discussion were Messrs. J. R. Cravath, M. G. Lloyd, F. J. Pearson, G. C. Keech, W. C. Bauer, E. H. Freeman and T. H. Aldrich.

The topic for general discussion at the February meeting will be "Illuminating Problems in Small Cities."

NEW YORK SECTION.

At a meeting of the New York Section held on January 12th, papers were presented as follows:—"Artificial Illumination as a Factor in the Production of Ocular Discomfort," by Nelson M. Black, M. D., a consulting oculist of Milwaukee, Wis.; "Physiological Points Bearing on Glare," by P. W. Cobb, M. D., physiologist of the physical laboratories of the National Electric Lamp Association, Cleveland, Ohio.; and "Reflection Coefficients," by Mr. Paul Bauder, of the National Electric Lamp Association, Cleveland, Ohio. These papers were discussed by Dr. J. E. Weeks, Dr. H. H. Seabrook, Mr. W. H. Gardiner, Mr. A. J. Sweet, Prof. S. W. Ashe, Dr. A. H. Elliot, Mr. H. T. Owens, Mr. Norman Macbeth, Mr. Bassett Jones, Jr. and Mr. E. L. Elliott.

The discussion on a paper by Dr. J. C. Pole, chief engineer of the Cooper-Hewitt Electric Company, Hoboken, N. J., entitled "Researches in the Photometry of Mercury-vapor Lamps," was postponed until the February meeting. At this meeting a paper entitled "Polar Curves of Finite Line and Surface Light Sources" will be presented by Mr. Bassett Jones, Jr. and a discussion on "Architecture and Illumination" will be led by Mr. Henry Hornbostel.

NEW ENGLAND SECTION.

The New England Section held its monthly meeting in Boston on January 9th, at which time a paper on "Physical Points Bearing on Glare" was read by Dr. P. W. Cobb, Cleveland, Ohio, and a paper entitled "The Illuminating Engineer and the

Fixture Designer" was presented by Mr. David Crawfield, chief fixture designer of the Pettingell-Andrews Company, Boston.

Among those taking part in the discussions were Mr. W. H. Blood, Jr., Dr. Louis Bell, Mr. R. C. Ware and Mr. Preston S. Millar.

PHILADELPHIA SECTION.

At the February meeting of the Philadelphia Section, Mr. Edward L. Simons will present a paper entitled "Artificial versus Sunlight for the Making of Motion Picture Films."

Exterior of Allegheny County Soldiers' Memorial.

THE LIGHTING OF THE ALLEGHENY COUNTY SOLDIERS' MEMORIAL.[1]

BY BASSETT JONES, JR.

The Allegheny County Soldiers' Memorial is located in that district of Pittsburgh known as Oakland. The structure forms the architectural center of a large group of monumental buildings some of which are completed and others of which are now under construction. The Memorial faces east on Fifth Avenue looking across Schenley Park and toward the immense Carnegie Library building and the buildings of the Carnegie Technical Schools beyond. North of the Memorial are The University Club and Pittsburgh Athletic Association buildings; back of it and to the West are the buildings of the University of Pittsburgh now partly erected but which will eventually form a magnificent background of classic structures rising tier upon tier to the brow of the steep hillside, where the present plans call for a temple-like building crowning what bids well to become an American Acropolis. The Memorial stands at the rear of an entire city block, the approach from Fifth Avenue being graded and landscaped to lead up to the Plaza like space directly in front of the building.

ARCHITECTURE AND CONSTRUCTION.

The structure is an imposing pile of majestic proportions in many ways reminding one of the famous tomb of Halicarnasus. The style of the exterior architecture is distinctly classic but is strongly infused with the personality of the designers.

The front entrance is flanked by two projecting wings each containing a room intended for meetings of the G. A. R. Posts. Over the entrance is a statue in bronze representing Victory in Peace modeled by Charles Keck. The main entrance foyer is rectangular in form with a barrel vaulted ceiling resting on a cornice supported by free standing columns. This foyer opens directly to the main auditorium and, on each end, to the memorial corridor extending along the other three sides of the building. The main auditorium, is a large room 120 feet clear span in

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, December 8, 1910.

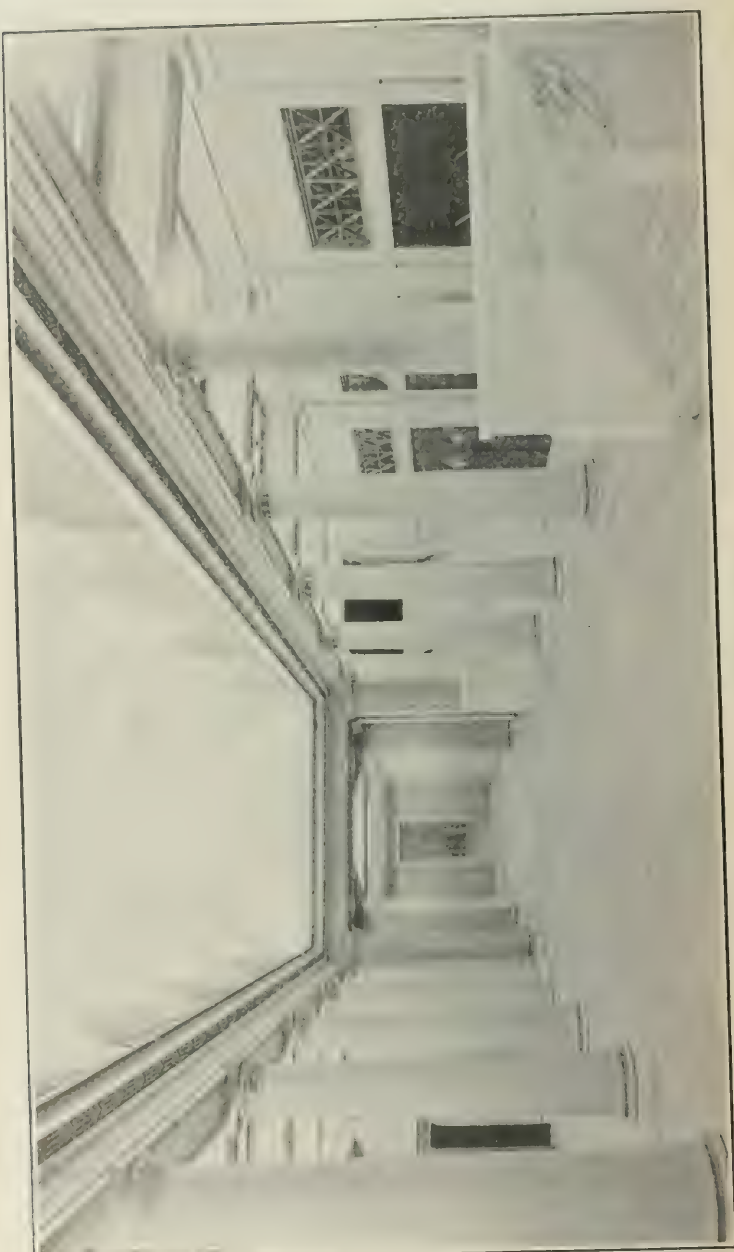

Fig. 1.—Entrance foyer at night.

Fig. 2. Memorial corridor at night.

the square and 65 feet from the center of the floor to the ceiling. The floor slopes to a stage at the rear. A large gallery extends around three sides of the room.

The auditorium is lighted during the day by seven immense one-piece plate glass windows in each of the four walls. These windows are 20 feet high, extending from a decorative band above the gallery to within 3 feet of the ceiling, each window being placed to look between two of the great exterior stone columns supporting the cornice, attic, and roof. Thus they provide an excellent view of the auditorium ceiling from the outside of the building.

The ceiling of the auditorium is broken into panels by deep plaster soffits covering the bottom chord of the trusses which support the floor of the banquet hall above. These panels are suspended from the steel work in the banquet hall floor and are thus only indirectly supported by the trusses. Each panel is entirely separated from the soffits by a slot six inches wide, and thus hangs free within the frame formed by the projecting trusses. The depth of these trusses, 12 feet, made it possible to obtain a clear space above the panels six feet high which was used in the illumination of the auditorium as will be described hereinafter.

The banquet hall which is reached by elevators and staircases in the four supporting corners of the structure, is 35 feet from floor to ceiling and is 74 feet square. The ceiling is divided into 49 square coffers, about two feet deep, the top of each coffer consisting of a decorative glass sash. The ceiling construction is hung from the steel work supporting the huge pyramidal roof above. Referring to Fig. 7, it will be seen that a gallery extends entirely around the upper portion of the hall. Under the floor of this gallery on each side of the hall are the corridors giving access to smaller offices, meeting rooms, kitchens, etc., along the outer walls of the building. Under the gallery at the rear of the hall are two smaller private dining rooms which may be made a part of the banqueting hall as indicated, the entire wall separating them from the main hall being collapsible and hung on trolleys.

A stage, the stairs leading to the gallery, and a promenade corridor are under the gallery at the front of the hall.

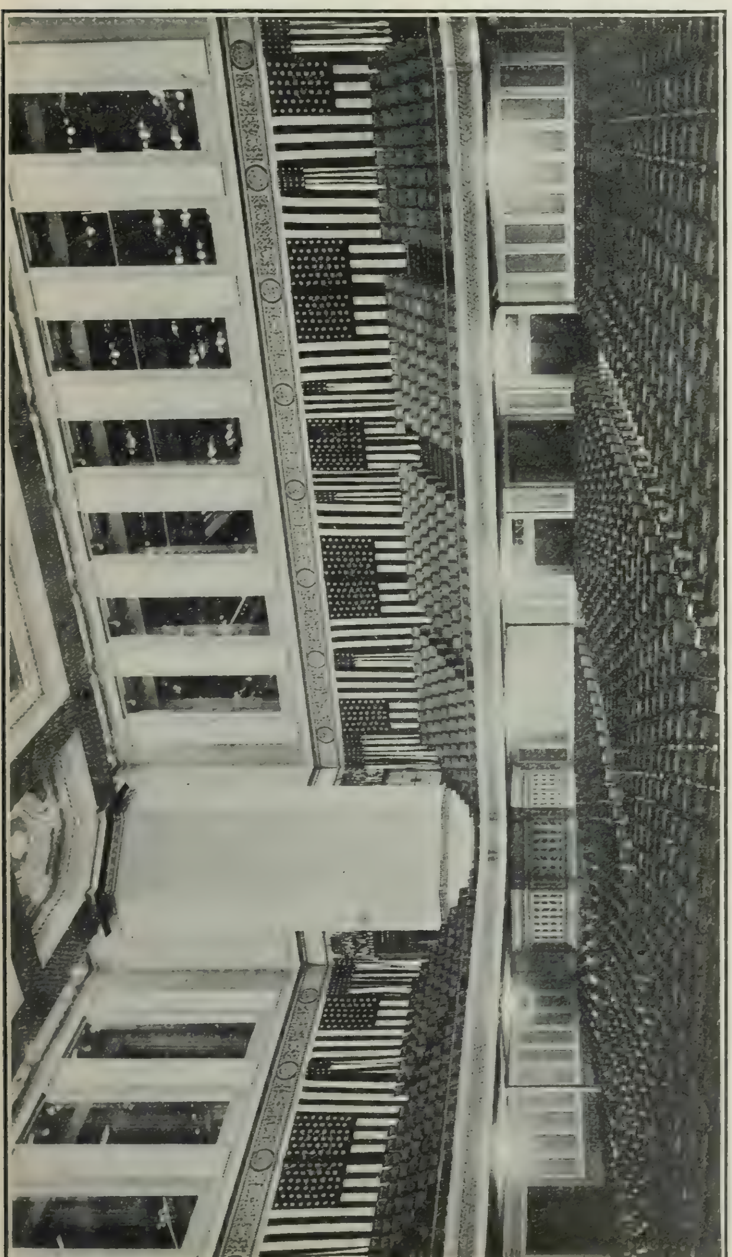

Fig. 3.—Night view of auditorium from stage.

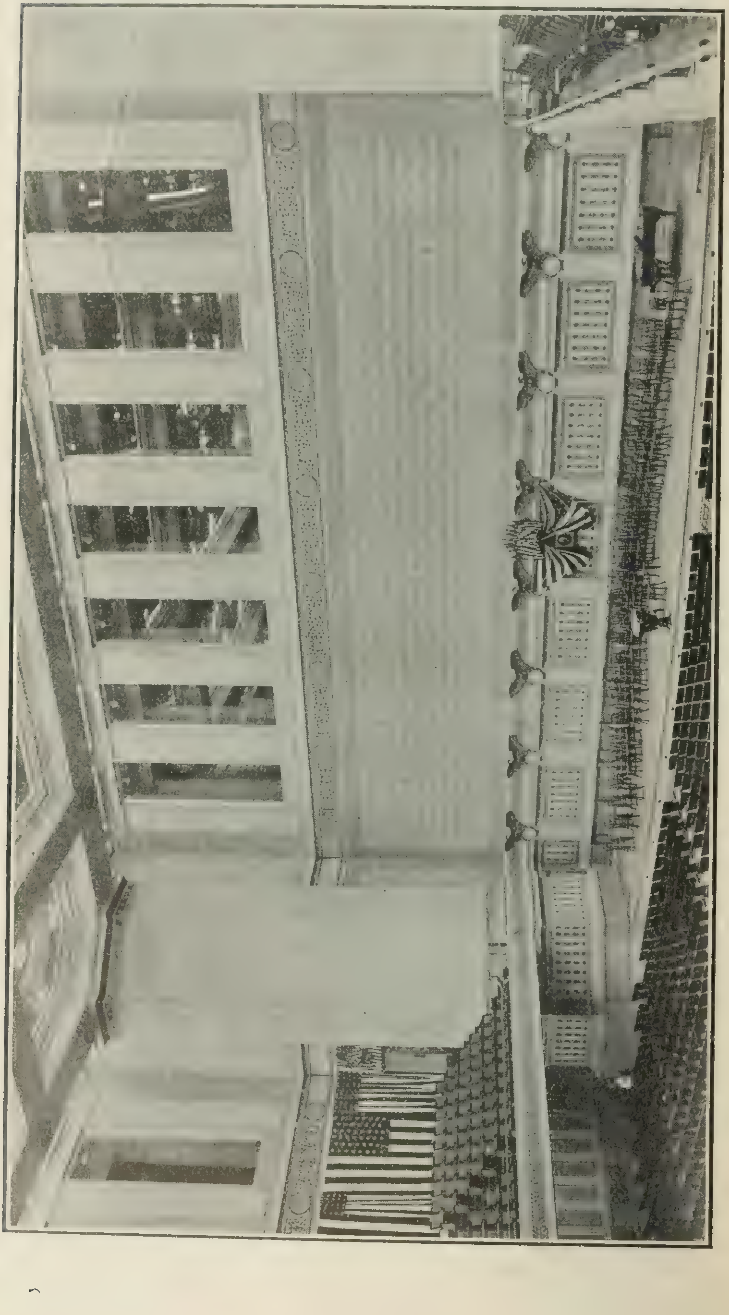

Fig. 4.—Night view of auditorium from rear gallery.

DECORATION-COLOR.

While the exterior of the building is almost severe in its simplicity, the interiors particularly the foyer, memorial corridor, auditorium and banquet hall are rich in decoration and ornament and are exceedingly rich in color. Nor does this richness of color in any way detract from the meaning of the monument, so skillfully has it been handled. There is no doubt, however, that the interior treatment of the Memorial will be a subject for much discussion. It is possible that nothing like it has ever been attempted before in this country so that in the matter of color treatment the building marks a very daring departure from modern practice.

It is known that the Greek architects were lavish in the use of bright colors, both on their exteriors and interiors—something like it was done by the Romans at Pompeii and by the Italians of the fifteenth century. But the use of elaborate color schemes has fallen more or less into disuse during modern times—probably largely due to a lack of imagination and courage on the part of designers and to ignorance of the real appearance of the ancient architectural masterpieces. However, with the rise of the science of archeology and the work of the resident schools in Greece and Italy it has become a fact of general knowledge that the chiefest effects obtained by the old masters were produced by the use of colors to accent natural light values.

It is therefore not surprising if the feeling on the part of the visitor when first entering the Memorial Building is one of wonder. The sensation produced is too new and unwonted not to be at first the cause of instinctive repulsion unless a keen imaginative sense can off-set the effect of novelty. One is confronted by bewildering patterns in reds, yellows, greens, and blues; in the mixed pigments, mauves, lilacs, carmines, oranges, and golds have been used lavishly. Bands of geometric patterns in yellows against a scarlet background,—mouldings picked out in blues and greens—scarlet wreaths and festoons bound with yellow against a pale blue panel—and so on. It sounds badly, does it not? But so carefully have the tones been selected and blended, so thoroughly have the laws of color harmony been followed that it is rarely that a second view will leave aught but admiration in the mind of the erstwhile critic.

The harmonizing value of black either by itself or in mixture with other pigments is entirely omitted from the color scheme, with the idea in mind that the unavoidable deposits from Pittsburgh's smoky atmosphere would soon introduce this tone.

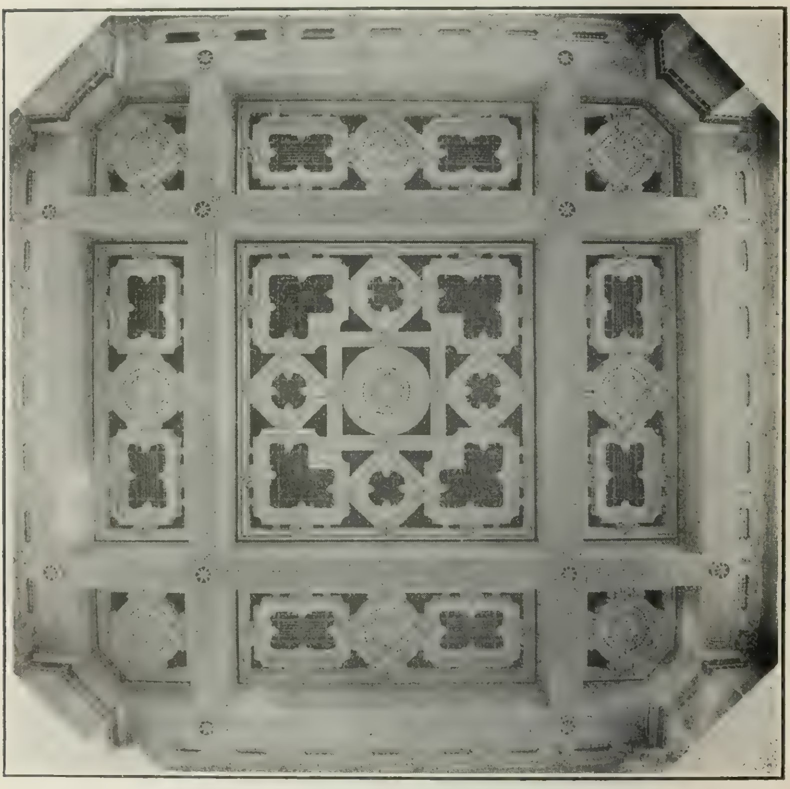

Fig. 5.—Auditorium ceiling by daylight.

Pictures can give one no conception of the coloring. It must be seen to be appreciated. To make this evident, examine the auditorium ceiling as shown in Fig. 5. The pattern on the truss soffits is bright yellow, the background red. The mouldings at the soffit heads are light blue and yellow. The panels are a soft opalescent green. The sashes have pale green cross-bars, and carmine mullions support the individual panes, which are gold

amber. About the cap of the four great corner pilasters are carmine mould bands. The pilasters themselves and the general tone of the walls are pale purple—almost lavender. But no description can convey the least idea of the tones employed.

GENERAL FEATURES OF THE ILLUMINATION.

It has seemed necessary to give the above account of the general design of the building in order to bring forward some conception of the nature of the lighting problem, but before proceeding to study the installation for lighting the foyer, the me-

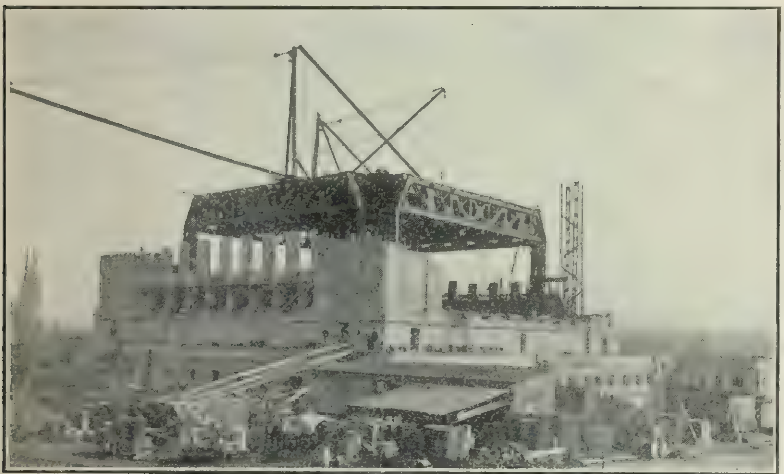

Fig. 6.—View during construction showing trusses for supporting the banquet hall.

morial corridor, the auditorium and the banquet hall, the author wishes again to harp on some general considerations.

In an article on "The Lighting of Period Interiors" published in "The American Architect" for March 30, 1910, I attempted to draw attention to the close relationship existing between a design and the light which enables one to see it, in these words:

"In an earlier article we mentioned the close relation that the arrangement of a lighting equipment should bear to the architectural design. Too much emphasis cannot be given to a principle so fundamental. It seems perhaps unnecessary to repeat the truisms that art makes its appeal solely through the channels of sense—to what it appeals and why it appeals being, of course, another question—and that the perception of the aesthetic ideal

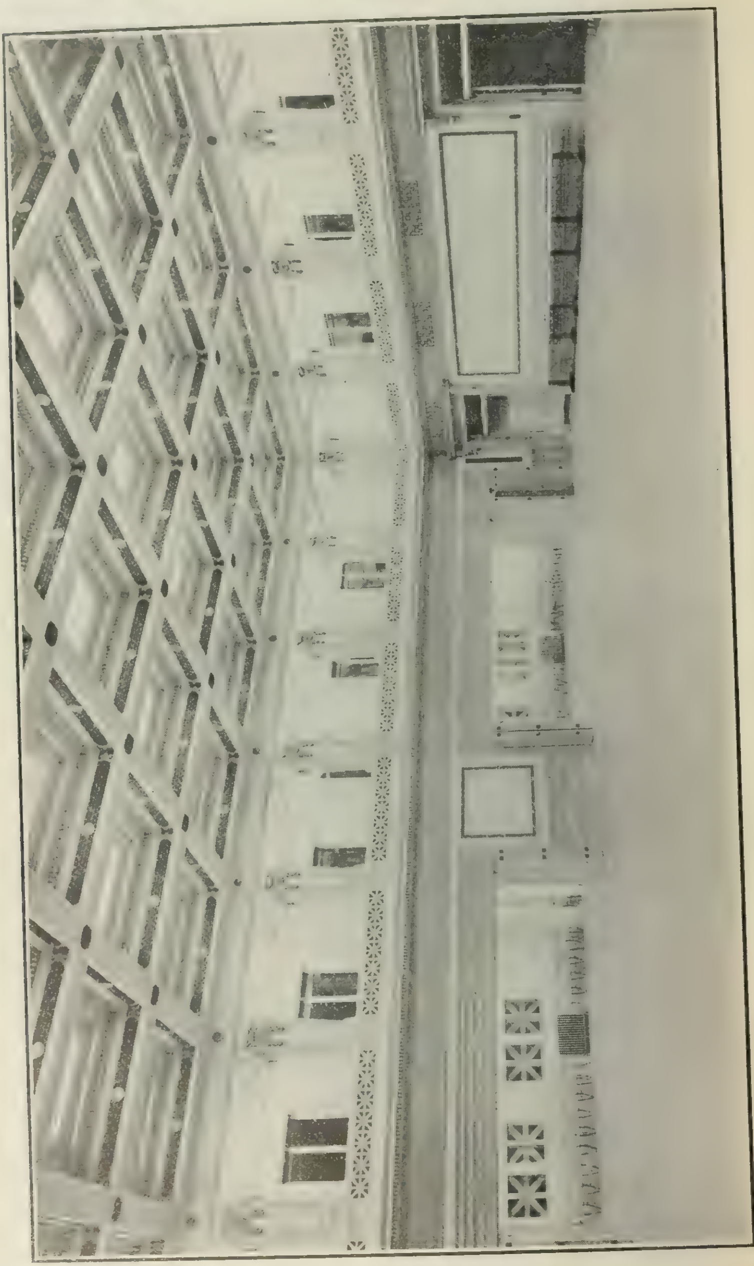

Fig. 7.—Night view of banquet hall.

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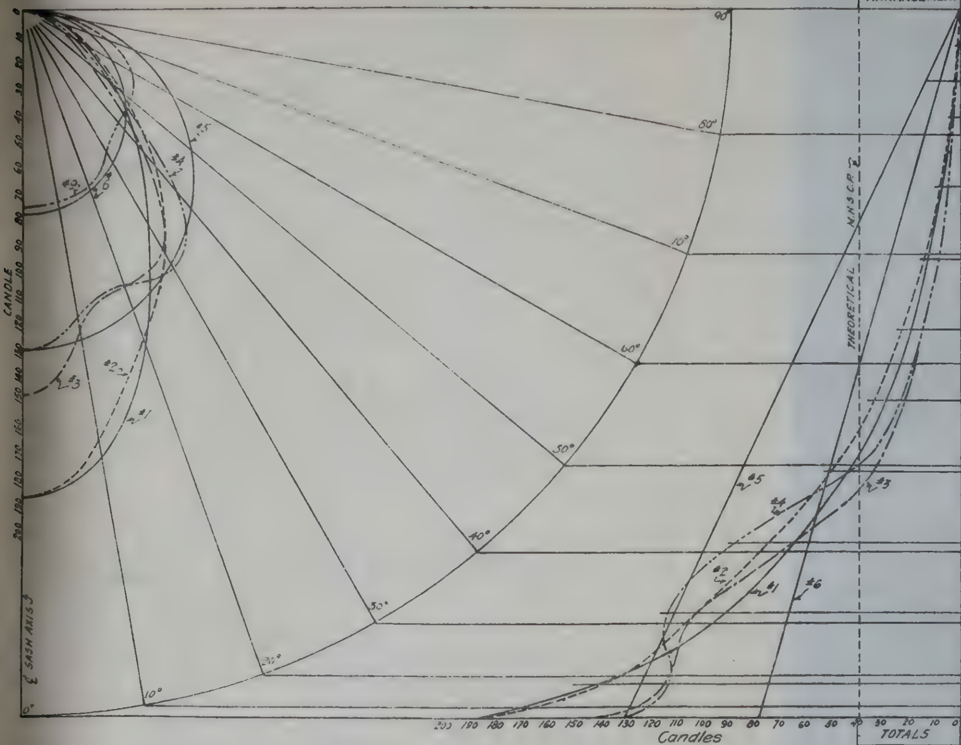

ARRANGEMENT	#1	#2	#3	#4	#7	#8
	MEAN CANDLES.					
	1.50	1.50	1.50	1.50	0.30	0.30
	4.50	4.50	4.00	3.50	0.85	0.85
	8.00	8.50	6.00	5.50	1.38	1.47
	13.20	14.50	9.00	9.00	1.90	2.10
	20.00	23.00	15.00	15.50	2.40	2.68
	29.00	34.00	22.00	23.00	3.00	3.75
	42.00	48.00	32.50	40.00	4.30	5.40
	64.20	74.00	65.00	85.00	6.45	8.05
	91.00	102.50	102.0	112.50	9.55	11.90
	142.00	139.00	112.50	112.00	14.80	20.40
TOTALS	415.40	449.50	369.50	407.50	34.93	56.81
M.H.S.C.P.	41.5	44.9	36.9	40.7	3.49	5.68
LUMENS	260	282	232	255	21.9	35.7
LUMENS GENERATED	586	586	586	586		
LUMENS LOST	326	304	354	331	13.8	
EFFECIENCY IN %	44.5	48.0	40.0	43.4		
% LOSS IN SASH			11.8	9.0	38.7	

LEGEND.

ARRANGEMENT #1. REFLECTOR 'C' WITHOUT SASH.
" #2. " 'D' " " .
" #3. " 'C' WITH SASH 23"X22" (3.5⁰).
" #4. " 'D' " " " " " .
" #7. " 'A' " " 6"X6". SAME GLASS USED IN ARRANGEMENTS #3 AND #4. GIVEN TO SHOW DECREASED LOSS IN SASH WITH FINAL ARRANGEMENT OF REFLECTOR RESULTS ONLY GIVEN A/C SMALL SCALE
" #8 " 'A' WITHOUT SASH.
POLAR CURVE #9 IS DRAWN TO SHOW HOW CLOSELY THE COSINE LAW MAY BE APPROACHED IN FINITE SURFACE SOURCES BY A PROPER SELECTION OF REFLECTOR AND SASH.

Fig. 8.—Tests of experimental reflectors.

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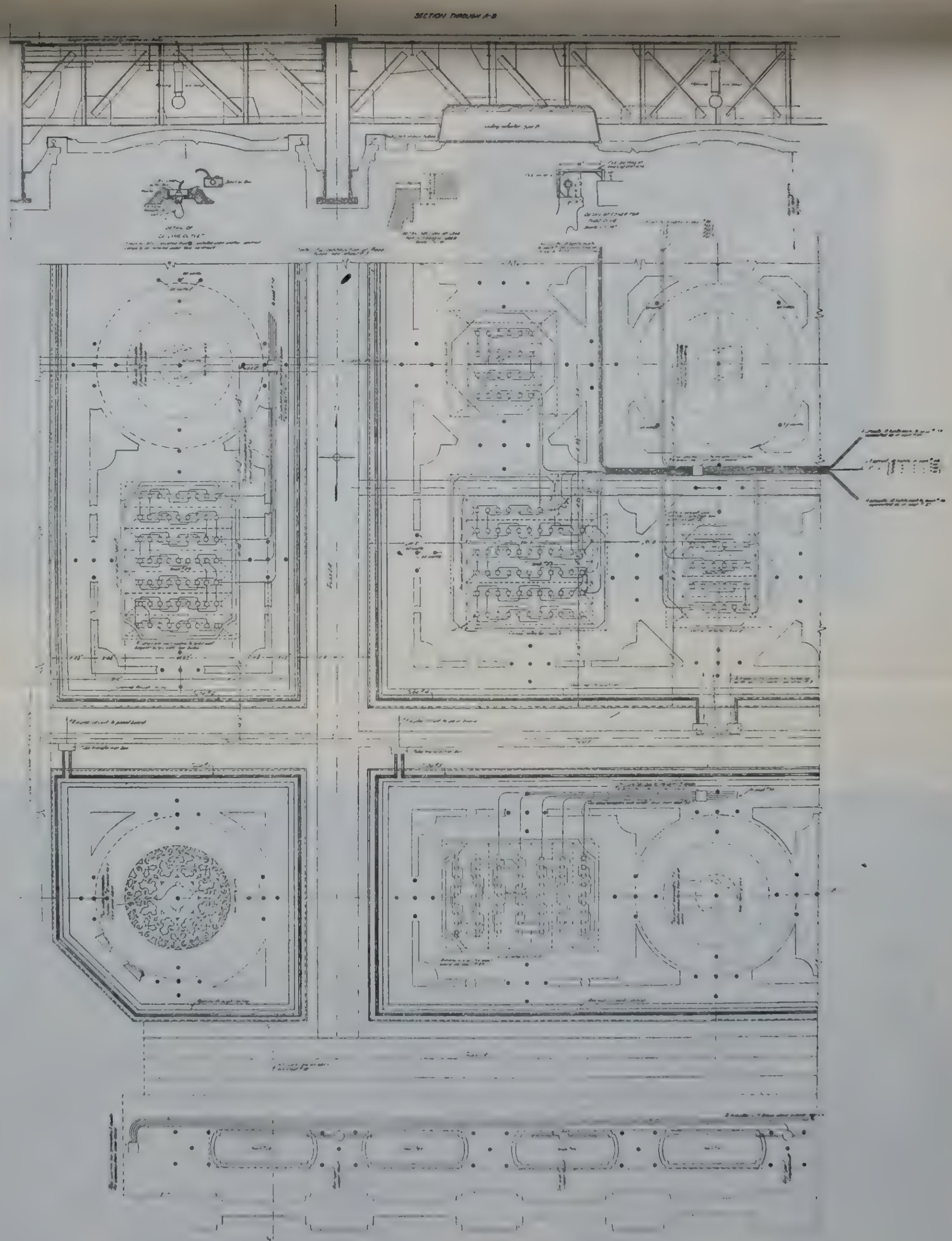


Fig. 9.—Quarter plan of auditorium ceiling[1]

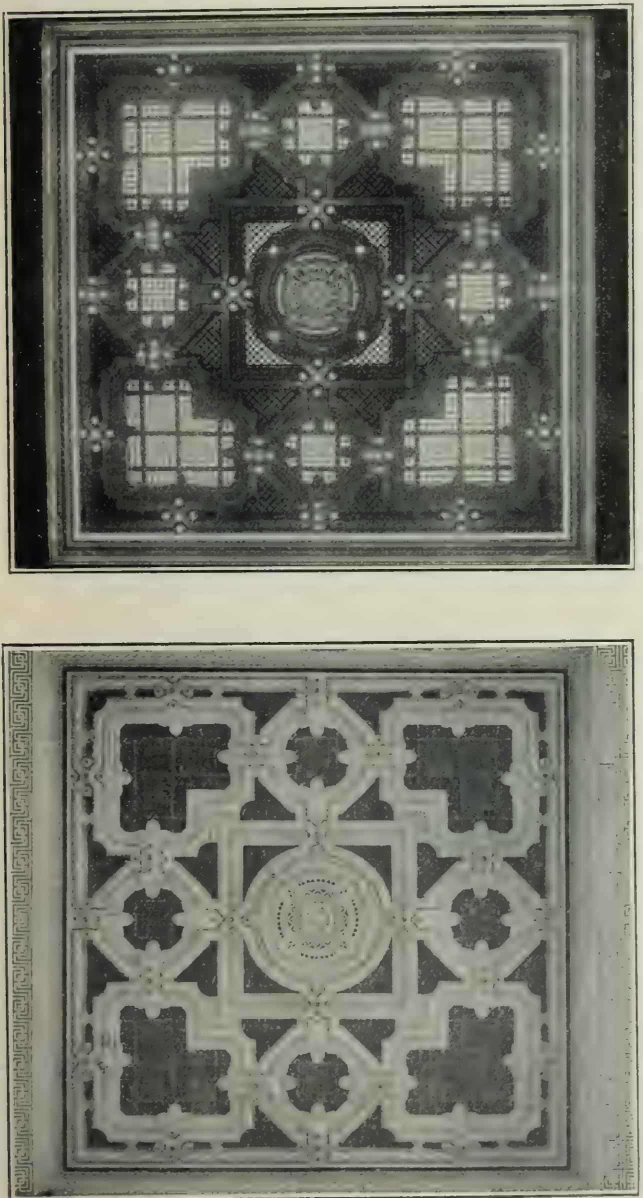


Fig. 10.—Daylight and night views of central panel in auditorium ceiling.

embodied in an architectural composition, depending, as it does on the visual sense, demands an appropriate and carefully studied relation of effects in light and shade. Reduced to its simplest terms, the sensuous aspect of beauty in architecture is a matter of the grouping of light values, excepting, perhaps, those purely spacial and geometric characters depending for their perception on eye parallax and other muscular reflexes; but even then the reflex is itself induced by the arrangement of the light stimulus."

"It is then evident that if the artist's embodied conception is to be properly translated into just the correct visual sensations that will arouse in the beholder the particular feeling the artist is attempting to convey, the means whereby these sensations are aroused must be exactly suited to the particular case. The ideal content attainable will be strictly limited by its sensuous vehicle whether this vehicle be sound or light, and hence no artificial restraint that will in any way interfere with or block off the required sensations should be imposed."

"We do not desire to go very deeply into the philosophy of the matter, but enough must be said to indicate the importance of the fundamental principle from which our discussion starts. This principle is not a principle of engineering, although engineering principles can without doubt aid us materially in achieving the desired end. The value of a knowledge of and ingenuity in applying the physical laws of light and the value of a knowledge of the character and limitations (chiefly the limitations) of available sources is, however, of importance in enabling us to obtain results that will free the architect from the shackles of precedent by making wider the range over which he can find a satisfactory vehicle for expression."

In the case of the Soldiers' Memorial a further step has been made in using the illumination itself—not only the light sources, but the actual light effects,—both in color and character, as an integral part of the decorative treatment. The light not only enables one to see the design, but of itself becomes a part of the design. The author believes he is correct in saying that never before has this idea been intentionally carried to such an extent. Practically speaking, the interiors of the building have been designed with the effects of the illumination and the practical demands of the lighting equipment kept constantly in mind. The

purpose was to use the electric lamp in such ways as to give the best possible value to the decorative quality of artificial light, combining in the general color scheme the colors of light emitted by various forms of light sources so as to produce a harmonious effect. The idea that gave rise to the conception embodied in the lighting of the Memorial Building was aroused by the decorative value of many recent colored electric signs. While these signs possess a certain bizarre character, there is embodied in the best of them a more or less crudely expressed sense of the artistic possibilities of color combinations in lamps. For outdoor display this possibility has reached its culmination in the so-called "scintillator," but has been entirely neglected in the treatment of interior illumination. While the application to a dignified architectural composition of a principle of decoration founded on the ludicrous, vulgar, and restless is an exceedingly dangerous proceeding, the experiment in the case of the Soldiers' Memorial is warranted by the extraordinary beauty and dignity of the result achieved. That the result is dignified and beautiful is proved by the effect on the audiences occupying the auditorium. The public behave in this room as in a church with a hushed movement and comment that is always produced by an object of real beauty no matter how lacking in aesthetic knowledge the beholder may be.

It is of course only in comparatively few instances that the use of colored light in the design can be attempted, but there are several interiors, notably in theatres and other similar auditoriums where some such treatment would have been desirable.

Not less daring did this idea seem to the writer when suggested by the architects than the then proposed architectural treatment of the principal rooms in the Memorial. The author is free to confess that he long doubted the possibility of achieving the results desired and believed that the effect would be decidedly disappointing. However, Mr. Hornbostel's enthusiasm and his undoubted genius eventually embued the writer with some of the same faith, and the result fully confirms the architect's emphatic belief in the beauty of his conception.

The problem, then, was to produce in these rooms a certain arrangement in light colors that would both take its place in the

architecture and serve the utilitarian purposes of making the design perfectly visible as well as fulfilling the needs of the uses to which the rooms would be put. Fortunately, the architects' appreciation of the value of light and their intimate knowledge of its limitations—the latter, an often neglected aspect of the problem of interior illumination, by the way,—made the working out of the solution both interesting and pleasant. The effect of shadows was studied with great care and results in a sharpness of detail and a correctness of perspective under artificial light that has not often been obtained. This is particularly true of the fine relief ornamentation on the auditorium ceiling, which in spite of the great distance from which it is seen, stands out with greater distinctness under artificial light than by daylight. This fact is *prima-facie* evidence that the design was conceived as lighted and has been executed so that it can be lighted as conceived. An idea of the interesting contrast between the appearance of this ceiling by day and by night can be obtained from Fig. 10.

PRELIMINARY WORK RELATING TO ILLUMINATION.

The results required of the illuminating equipment were so varied and so novel that the writer found himself quite lacking in data applicable to the problem. Nor could any existing installations be found similar to that proposed from which data could be obtained either by observation or by test. A thorough search of the literature of illumination brought forth nothing that could be accounted an aid in the work of designing the equipment.

In order to plan intelligently the engineering features of the installation it was apparent that a practical study of reflection, absorbtion and diffusion of light by various forms and kinds of glass, and a similar study of reflection of light from various opaque surfaces were essential. The literature of light color and the modification of light color by colored transparent screens was so highly theoretical and lacking in detail that it was also necessary to carry on a careful investigation of the effect of such screens made of commercial colored glass.

One of the principal requirements of the installation was the partial lighting of the auditorium and the entire lighting of the

banquet hall through sashes of glass let into the ceiling construction. It was demanded that the flux through these sashes should

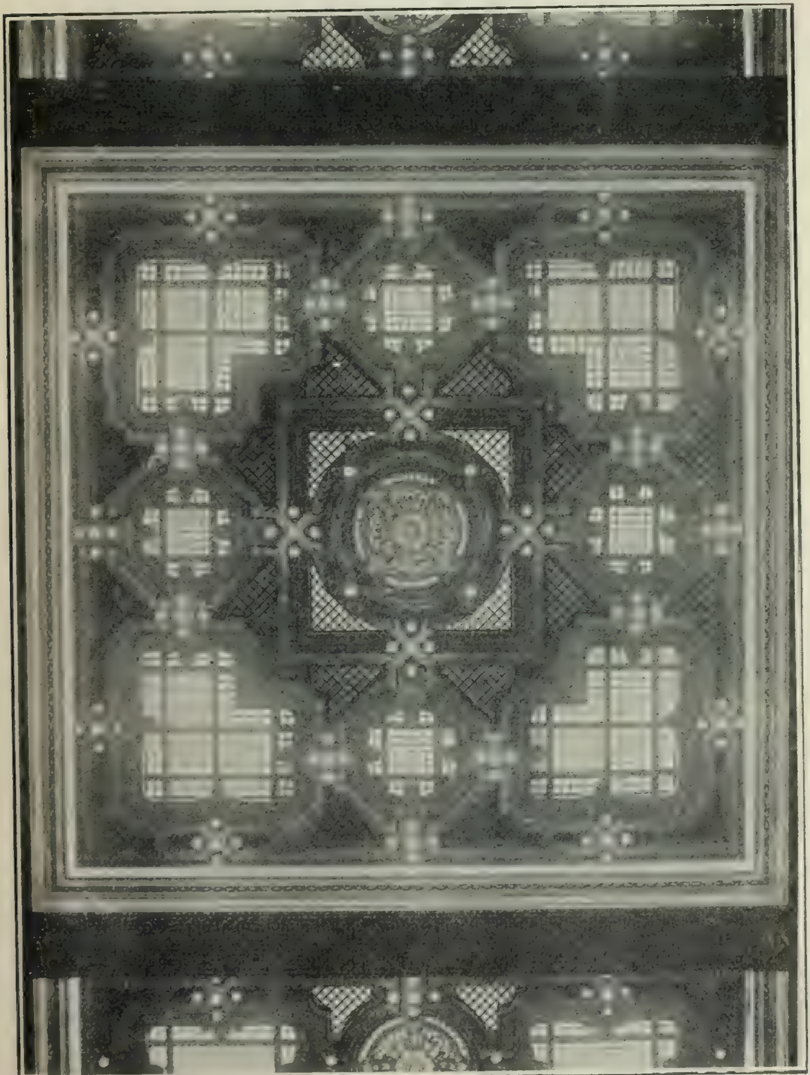


Fig. 11.—Part of auditorium ceiling at night.

be so distributed that there should be nothing in their appearance to lead the beholder to appreciate the fact that the light originated

at given points above them. There must be no appearance of "spots" due to the image of the illuminant or the intrinsic brilliancy of the light units employed. It is a simple matter to produce such a result when the total effective flux required is not large, but when one is required to produce a relatively intense illumination at considerable distances from such sources the question of power consumption, efficiency and operating costs becomes a large factor in the problem. Furthermore, in order to enable the other features of the ceiling design to take their proper place in the ensemble, it was necessary to avoid all appearance of great intrinsic brilliancy in the light source and so to direct and distribute the light as to void loss of shadow. Again, the color of the light must be suited to the color of the surface illuminated and not disturb the color balance, and, lastly, the color of the light source itself must harmonize with the modified colors of the surrounding architecture. This was no simple problem.

It will be at once evident that there are two controlling factors in this case; first, the kind of glass used in the sashes and, second, the arrangement of the lamps with relation to the glass surface. Several model reflectors with reflecting walls extending down to the edge of the experimental sash were therefore built of white cardboard, and the writer experimented with these models in the hope of finding some way of avoiding "spots" or streaks of high brilliancy without excessive loss of flux.

Various lamps were used, but it soon appeared that with the lamps hung over the sash, the greater the "downward" candlepower, the more brilliant the "spots." Even the incandescent lamp showed "spots" when hung over a sash of any but the denser forms of opal and art glass, and the nearer the glass the brighter the spots. On the other hand, the higher the lamps were placed above the sash the greater loss due to dispersion and absorbtion in the reflecting surfaces. If the lamps were not placed over the sash then critical angles and reflection from the sash surface caused a still further lowering of the efficiency of the arrangement, and unless elaborate precautions were taken the spots still appeared so soon as the lamps could be seen by moving to one side or the other of the sash axis. Finally the spots were entirely obviated and the efficiency was considerably

increased by a particular arrangement of the reflector. Numerous other forms were tried and either did not entirely remove the "spots" or cast shadows on the sash.

The results of the tests on the first successful cardboard model reflector and sash are given in Fig. 8. The efficiency of the final arrangement approximates so closely to 45 per cent. that it was assumed that, with a reflector having a reflecting surface of higher efficiency than cardboard, a value of 40 per cent. could be attained in practice with clean glassware. It will be noted that the final arrangement, due to a decreased reflection loss in the sash, increases the efficiency by 3.5 per cent.

The general character of the reflector having been thus determined, the next point to be considered was the selection of a sash glazing which would diffuse the flux transmitted so as to produce the proper shadow effects in the relief mouldings surrounding the sashes and in the mouldings used to decorate the sides of the soffits. This was found in two types of sheet glass. Readings plotted in curve 4, Fig. 8 were taken using a sash of the form of glass actually used. The close approach of this curve to the theoretical curve of a perfectly diffusing medium is readily apparent. The curve could have been still more rounded out by the use of a different glass had this been advisable. See curve 9, in Fig. 8. If the polar surface for the entire source sufficiently approximates a sphere as in the case with No. 9, then of course the calculation of the flux density at any point may, with close approximation, be reduced to a simple application of the cosine law. However, in general, such a surface can only be obtained in practice by increased loss of flux, and may not always produce the best shadow effects.

The color scheme in the ceilings of both the auditorium and the banquet hall required that the color of the lighted sashes be a golden tone. This color could be obtained in two ways, first. by using a sash glass containing relatively little coloring matter, thus reducing the loss through absorption, and a low-efficiency lamp giving a maximum of light in the yellow, or, second, by increasing the color in the sash glazing and employing a high-efficiency lamp giving a relatively white light. The best results obtainable with commercial lamps resulted from the combination of tungsten lamps and a sash glazing of the 45 amber tint.

The carbon arc lamp was considered and abandoned due to the inherently low efficiency of the alternating current lamp and the great loss in the sash due to excessive coloring matter required to correct the color of the light. The flame arc would be too noisy and in addition its flickering would destroy the solid luminous appearance of the sashes. Furthermore special ventilating arrangements would be necessary to carry off the gases

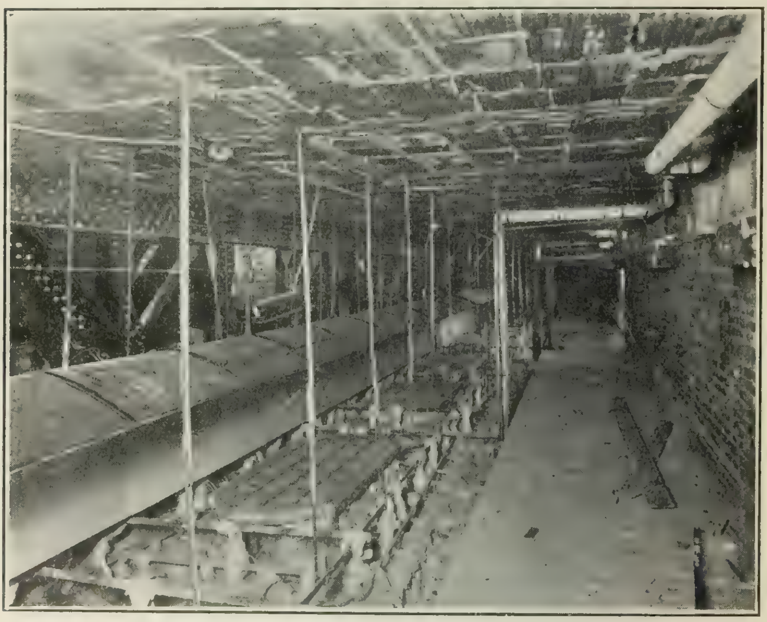
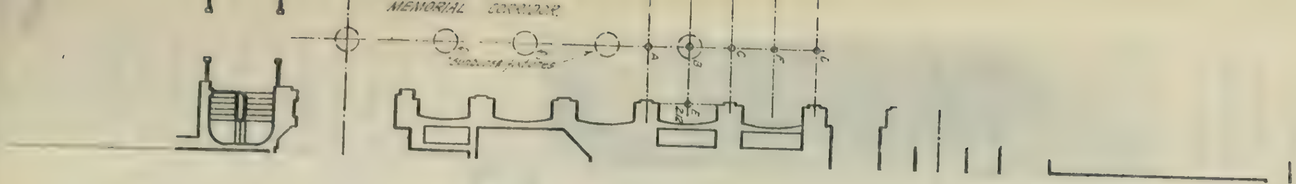


Fig. 12.—View above auditorium ceiling showing mercury vapor lamps and reflectors.

generated and the constant attention and trimming would be a source of expense. The use of arc lamps was also mitigated against by the necessity of employing a large number of small light units so that the failure of several lamps or the blowing of a fuse would not produce noticeable effects.

The painting of the interior of the reflectors received much attention and various samples were tested until a highly efficient reflecting and diffusing surface was obtained the finishing coat of which consisted of an imported zinc oxide ground in turpentine only. Great importance was attached to the fact



MEMORIAL CORRIDOR
A
B
C
F
C
E
212

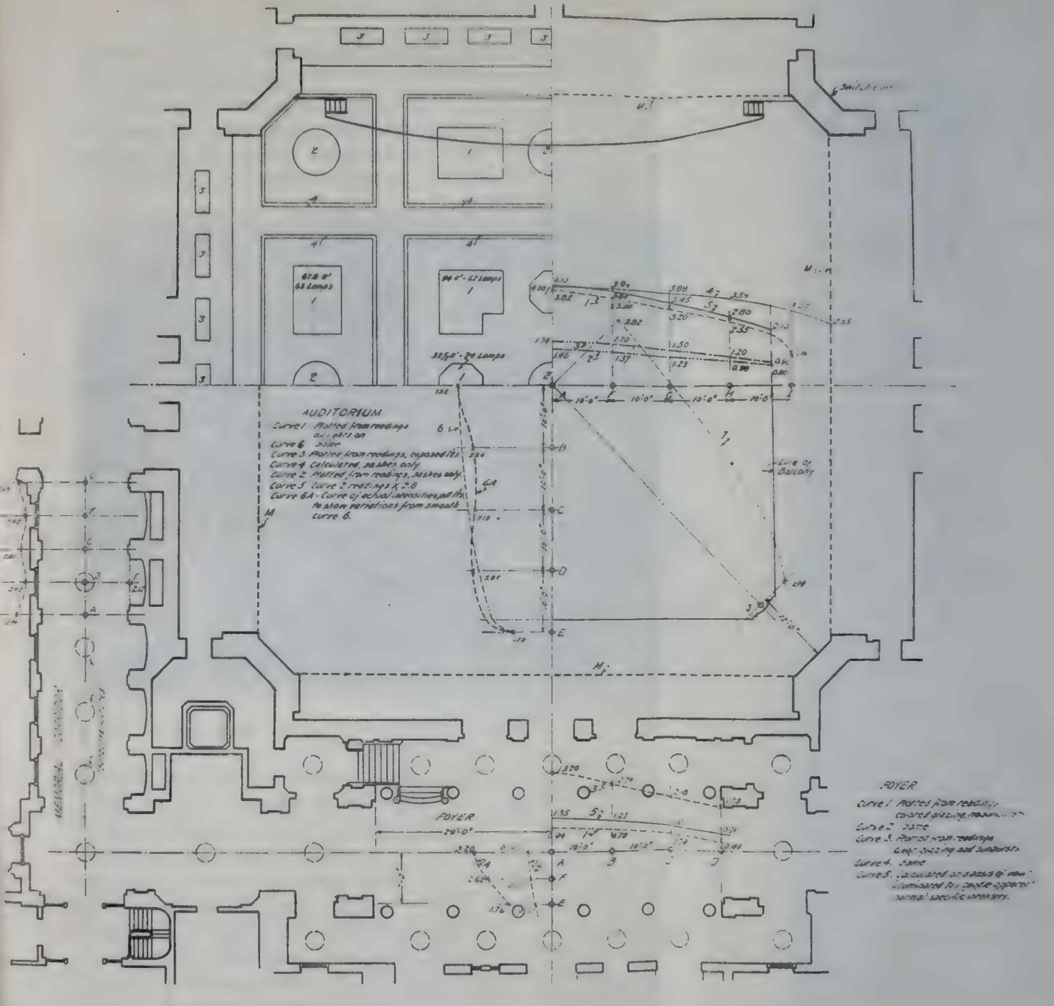


Fig. 14 —Part plan of first floor.

that this zinc oxide thus mixed retains a pure white color over a long period, and maintains a high reflection co-efficient.

Having thus determined the form of the equipment and the character of glass to be used the next point to be taken up was the quantity of flux needed in each case. This could be found approximately by the flux method, assuming certain intensities of

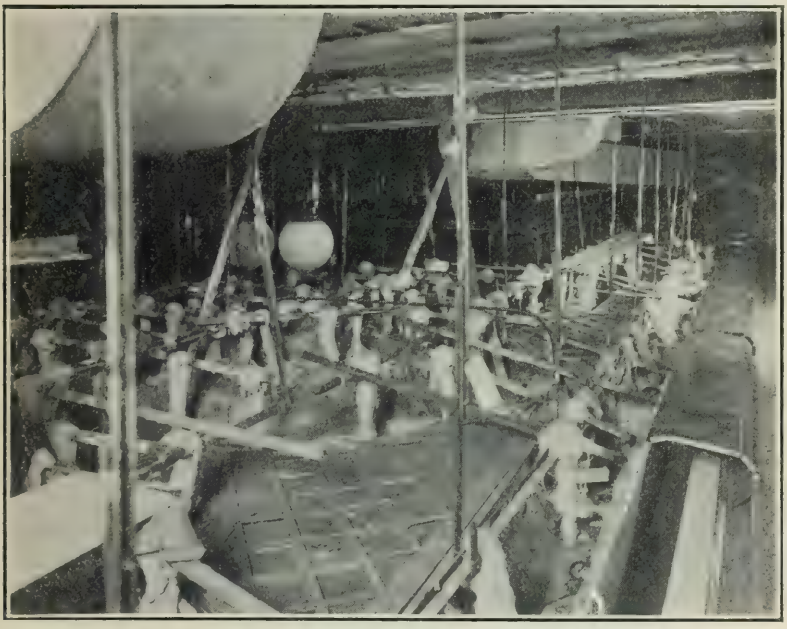


Fig. 13.—View above auditorium ceiling showing box reflector, flame arc lamps, and nitrogen vapor tube lamps.

incident light on the ceiling, walls, and floor. Certain definite requirements as to the illumination over certain areas had to be met, however, and a question arose as to the possibility of obtaining these values of illumination with a finite surface source emitting a given flux distributed in a certain way. The writer therefore made a study of such sources and obtained certain formulae for calculating the density of light flux. The results of this study, such as they are, have been presented in two papers already published in the TRANSACTIONS, namely, "Mathematical Theory of Finite Surface Sources," April, 1909, and "On Finite Surface Sources," May, 1910. The curves shown in Figs. 14

and 15, indicate the relationship between the actual illumination under the conditions existing at the time of test and the calculated illumination.

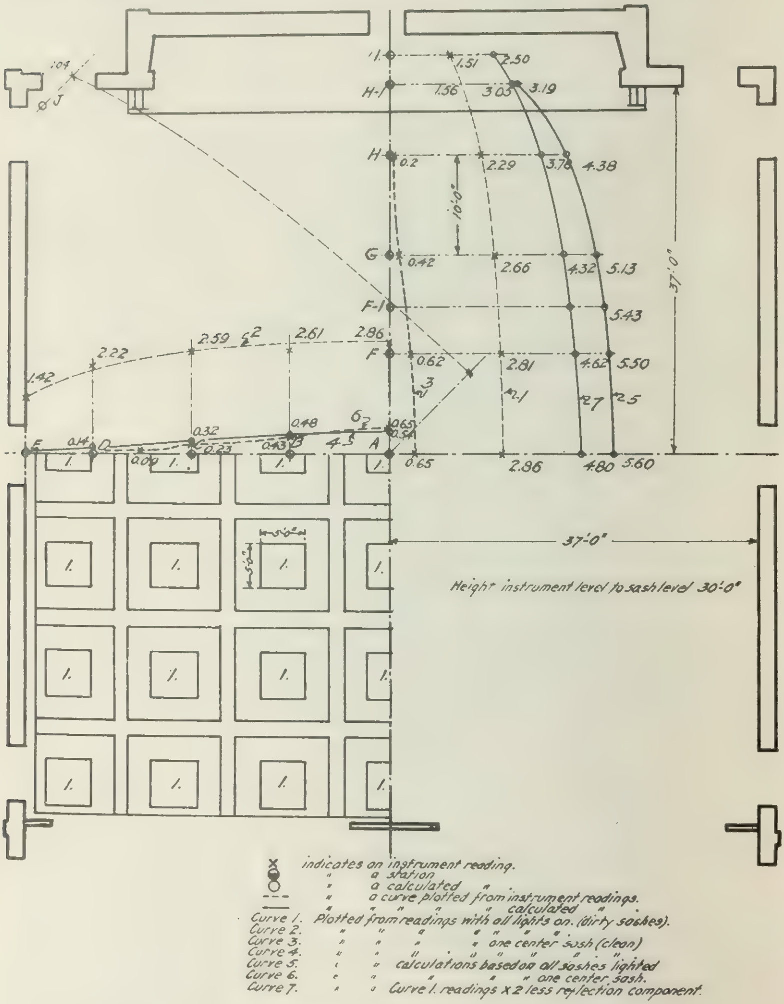


Fig. 15.—Plan of banquet hall.

LIGHTING OF THE AUDITORIUM.

The view of the ceiling, which is the principal architectural feature of this room, could not be obstructed and hence in any

case the use of hanging lighting fixtures had to be avoided. The treatment of the ceiling centers around the light centers which are also architectural centers when the room is lighted by daylight from without. These nine centers consist of circular panels of rich pierced plaster ornament above each of which are suspended two 18-amp. flame arc lamps, so located and equipped as to cause the plaster lines to stand out in bold relief against a brilliant flickering background. The general effect is that of a scintillating jewel of intricate pattern. One of these circular panels forms the central feature of each of the large panels into which the entire ceiling is divided as before mentioned by the deep beam soffits under the steel trusses supporting the floor above.

A group of glass sashes is arranged around each of the flame arc panels and forms a design of geometrical surfaces broken up into small figures by the sash frames. A box reflector of the type above discussed is placed over each sash.

Each of the main rectangular panels, consisting of a flame arc center and its group of sashes, is framed by a concealed nitrogen vapor tube lamp provided with a reflector that projects the light through a slot entirely surrounding the panel. Each panel is thus bordered by a band of rose-colored light.

The ornamental plaster mullions separating the sashes in each panel are provided with plaster rosettes equipped with exposed incandescent lamps employed to accent architectural features and show off the elaborate decorative treatment of the plaster work.

Glass panels are located close to the side walls one over each window and over each is provided a parabolic reflector containing a 400-watt mercury arc. The light from these lamps is directed against the walls of the room and through the windows, and is so modified by the glass in the panels as to acquire a pale sky blue tone.

No one who has not seen this room lighted can imagine the grandeur of the effects, both from the interior and the exterior of the building. As one approaches the building from without the glory of the ceiling is seen only through the streams of light flooding from the windows between the columns of the majestic facade. The full splendor of the interior is perfectly set off by the artificial light. The wonderful color treatment of

the walls receives a new interpretation, becoming soft and rich in the flood of golden light that is thrown upon it. Each of the large panels seems to be suspended free in the space marked out for it by the beam soffits, while the entire ceiling is apparently framed by a border of soft moonlight.

The lighting of the auditorium is controlled by switching devices in a closet off the stage so that any feature of the lighting may be turned on or off at will. It is intended that either the light from the glass sashes or the light from the exposed lamps under the ceiling will be sufficient for ordinary purposes while the entire lighting system will be used only on special occasions. But, as a matter of fact the illumination has proved so popular as an exhibition in itself that it has been featured on every occasion, the audience usually remaining to view the various effects.

The cost of installing the auditorium lighting was remarkably low, as the cost of fixtures appropriate for lighting this immense room would have almost equalled the cost of the present illuminating equipment of the entire building.

Fig. 9 shows a cut of a large scale quarter plan and section of the installation above the auditorium ceiling. This should be compared with Fig. 14, in which is shown a quarter of the ceiling with relation to the room plan, and with Fig. 5. In Fig. 14 the sash areas over which the box reflectors are placed are indicated by the numeral 1, the pierced plaster grilles over which the flame arc lamps are placed are indicated by the numeral 2, the sashes over which the mercury arcs are placed are indicated by the numeral 3, and the slots at the side of which the nitrogen vapor-lamps are placed are indicated by the numeral 4.

The sash reflectors were arranged so that each lamp trough and its diffusing equipment could be lifted bodily out of the reflector. Unfortunately certain unexpected difficulties were met in the installation which required further changes after the reflectors for this room were delivered. The reflector walls are generally perpendicular instead of sloping which somewhat cut down the efficiency of the device.

The nitrogen-vapor tube lamps, mercury arcs, and flame arc lamps are used solely for effect, efficiency not being considered, since the particular effects desired could not be ob-

tained in any other way. To use incandescent lamps with color screens in place of nitrogen tubes and mercury arcs would require the use of very expensive screens of specially burned glass without any certainty that any one melt would have produced the correct tint. Furthermore, the exact character of light required can not be attained by any such method. Of course no substitute can be found for the flame arc lamps that will give a scintillating flux.

The smaller sashes of irregular pattern (see Fig. 5.) were left open to the space above the ceiling and are lighted in an irregular manner by the flame arc lamps, thus relieving the ceiling from a monotony that it would otherwise have exhibited. The amber glass in these sashes has the appearance of burnished copper when lighted. Some interesting effects have been obtained by covering a few of these sashes by thin developed blue print paper the two tints transposing the light transmitted from the flame arcs into an exquisite pale green.

Some difficulty was experienced with the pierced plaster grilles under the flame arc lamps because the contractor for the plaster work had made the castings too thin. After some experimenting, and as a temporary device, the grilles were covered above with thin cheese cloth which prevents the construction of the ceiling from being seen. The cheese cloth is entirely disguised and gives a solid appearance to the grilles. These grilles will eventually be covered with circular sashes of deflex glass.

Frosted-tip tungsten lamps were first used in the rosettes under the ceiling but the great intrinsic brilliancy and excessive whiteness of the light from these lamps when contrasted with the generally soft yellow tone of the rest of the illumination produced unfortunate results and with the exception of the center lamp in each group, they were replaced with 8 c-p. frosted-bulb carbon-filament lamps.

Thirty different effects can be obtained in the lighting of this ceiling, fourteen of which are really beautiful. The most interesting series of color changes is obtained by starting with the mercury arcs alone, and adding the remainder of the illuminants in the order following: 1. Nitrogen vapor lamps; 2. flame arcs; 3. sashes; 4. exposed incandescents. The most remarkable effect

is obtained by using only the nitrogen-vapor lamps and flame arc lamps. The ceiling then appears like a huge decorative grate above which great fires are burning. The maximum intensity on the floor then reaches 0.7 foot-candle. Adding the mercury-vapor lamps to this combination does not change the illumination on the floor, due to the form of the reflectors used with these lamps, but the effect produced is most wierd and profoundly alters the color of the walls to a grey blue. The light from the nitrogen-vapor lamps so completely detaches the panels from the ceiling that they appear actually to float in their frames and the slight flickering of the light that sometimes occurs seems to set them moving.

There are two general color effects obtainable in the illumination of this room, each of which may be varied through several tones; these are rose-gold and silver-blue.

The maximum intensities of illumination on the floor for different combinations, readings being taken at station A, Fig. 14, were as follows:

1. All lamps in use	3.82 foot-candles
2. Exposed incandescent lamps and sashes	3.10 foot-candles
3. Sashes only	1.46 foot-candles
4. Exposed incandescent lamps only	1.74 foot-candles
5. Nitrogen tubes only	0.40 foot-candles
6. Flaming arc lamps only	0.30 foot-candles

The above readings were taken directly after the work was completed and with a large amount of accumulated dust and dirt on the sashes. The results are therefore the worst that can be obtained, since once the sashes are cleaned the box reflectors will prevent any serious lowering of the intensity due to a similar cause. The loss due to dirt amounted to at least 20 per cent. of the lamp flux.

This loss was estimated in the following manner. On page 293 of Vol. V. of the *Transactions* for May 1910, will be found a formula for calculating the normal illumination at a point on a line drawn perpendicular to the center of a square source whose side is $2a$, when the point is at a distance h below the source. It is

$$I = 4i\left[\frac{a}{(h^2+a^2)^{1/2}}\tan^{-1}\frac{a}{(h^2+a^2)^{1/2}}\right]. \qquad (1)$$

Where i is the apparent illumination at unit distance perpendicular to unit source area, or specific intensity.

As an approximation assume that the illumination normal to the reading plane at its central point is due to a flux evenly distributed over the plane of the ceiling between the lines M-M in Fig. 14. One may safely assume a reflection coefficient in this room of not over 0.25—the floor contributes practically nothing, being covered with dark green upholstered chairs. As that component of measured I due directly to the ceiling, there is obtained the value.

$$I = \frac{1.46}{1.25} = 1.21$$

also $a = 50$, $h = 65.0$. Substituting in (1),

$$I = 1.21 = 4i\left[\frac{50}{(4,225 + 2,500)^{1/2}} \tan^{-1} \frac{50}{(4,225 + 2,500)^{1/2}}\right]$$
$$= 4i[0.568 \times 0.516],$$

whence $i = 1.03$.

The total area M-M is 8,836 sq. ft. The total net glass area in 1,000 sq. ft. Hence the apparent specific intensity per sq. ft. glass is $8.83 \times 1.03 = 9.10$ candles. The flux emitted per sq. ft. is therefore, $3.14 \times 9.10 = 28.574$ lumens, and the total flux emitted by the sashes is 28,574 lumens.

At the time this test was run the lamps in the reflectors were new and operating at approximately the proper voltage. Since there were 858 60-watt clear-bulb tungsten lamps so used, the total flux emitted by them was nearly 275,000 lumens. The approximate efficiency of the reflectors and sashes was therefore $\frac{28,574}{275,000} = 0.104$, or practically 10 per cent.

If, then, it be assumed that, allowing for the change in shape mentioned above the efficiency of the reflector with clean sash is 35 per cent., and deducting 20 per cent. of this for flux obstructed by mullions and plaster projections, the net possible useful efficiency is 28 per cent., or the net useful flux is 77,000 lumens. The actual loss of flux through dirty sashes was therefore somewhere between 18 and 25 per cent. of the generated flux.

The illumination curves shown in Fig. 14 were plotted from the average of five readings at each station on a plane 3.5 ft.

above the floor. The illumination of course drops off rapidly at stations E and I directly under the balcony. Curve 1 is taken with all lamps in use. Curve 2 is taken with sashes only. Curve 3 is taken with exposed incandescent lamps only, before the 25-watt frosted-tip tungsten lamps had been replaced with 8-c-p. frosted-bulb carbon filament lamps. Curve 4 is a curve calculated for the sashes only by means of the formula given above assuming that the total flux through the sashes, figured on a basis of 28 per cent. efficiency, is averaged over the entire ceiling area, within the lines M-M. This should be compared with curve 5 which is curve 2 with the intensity at each station multiplied by 2.8 to allow for loss by dirt.

In calculating the illumination plotted in curve 4 the following constants were used: The total glass area is 1,000 sq. ft., the total flux transmitted on a basis of 28 per cent. efficiency is 77,000 lumens. The flux transmitted per sq. ft, is 77 lumens. The apparent specific intensity per sq. ft., assuming a perfect spherical polar surface, is therefore 25 foot-candles. Averaging the flux over the total ceiling area of 8,836 sq. ft. within the lines M-M, Fig. 14 there is a flux per sq. ft. of almost 10 lumens and an apparent specific intensity per sq. ft. of 3 foot-candles. This is the value of i used in calculating the intensities plotted in curve 4. The reflection coefficient has been taken at 0.25 and is assumed constant.

Considerable deviation between these two curves is to be expected particularly near the side walls, but it should be noted that they are of the same general character and that the flux in the hypothetical case (28 per cent.) is nearly three times the flux in the test case. (10 per cent.)

The 112 groups of rosettes on the under side of the ceiling were first equipped with one clear-bulb 40-watt tungsten lamp and four frosted-tip 25-watt tungsten lamps per group—a total of 112 40-watt, and 448 25-watt lamps. As mentioned above, the 25-watt lamps were afterwards exchanged for 8 c-p. frosted-bulb carbon-filament lamps.

The power consumption per sq. ft. of floor area is, for the sashes, 4.03 watts; for the exposed incandescent lamps, all tungsten 1.20 watts, and for part 8 -c-p. carbon lamps, 1.14 watts.

The total power "let loose" above this ceiling including the exposed incandescent lamps amounts to 117.20 virtual kilowatts with all lamps in use.

LIGHTING OF THE BANQUET HALL.

The lighting of the banquet hall was a comparatively simple matter compared to the lighting of the auditorium—no special difficulties were anticipated, and none were met.

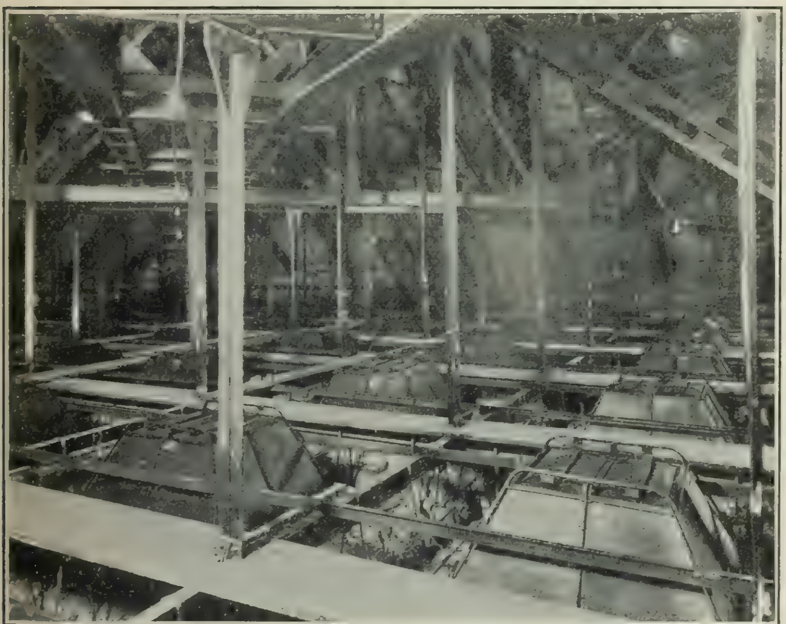


Fig. 16.—View above banquet hall ceiling showing reflectors.

The appearance of this room by night is truly remarkable. It is extraordinarily festive and gay and has an almost toxic effect on the beholder. Its keynote is joyousness, and when enlivened by a dance or a feast it is a wonderful sight.

As above explained, there are 49 glass sashes in the banquet hall ceiling,each sash forming the top of a ceiling coffer. The area of each sash is 25 sq. ft. from which 10 per cent. should be deducted for sash bars and mullions, leaving 22.5 sq. ft. net glass area per sash—a total glass area of 1,100 sq. ft. Above

each sash is a box reflector similar to those used over the sashes in the auditorium ceiling. Each reflector contained eight 40-watt clear-bulb 112-volt tungsten lamps. In Fig. 16 is shown a view of the space above ceiling of the banquet hall.

A plan of the body of the banquet hall is reproduced in Fig. 15. On this is shown a quarter plan of the ceiling, the sashes being indicated by the numeral 1. Illumination curves are also given on this plan. Curves 1, 2, 3, 4 and 7 were plotted from the readings given in the figure. Curve 7 is plotted from the readings in curve 2 corrected for reflection and multiplied by 2. Curves 3 and 4 were plotted from readings taken with only the central sash in use. In these last tests the central reflector was equipped with eight 60-watt lamps and both the reflector and the sash were carefully cleaned. The dip in curve 4 between stations C and D is due to the fact that the curtain wall in the reflector between the rows of lamps is set along the A-I axis and at this point partly cuts out the light from the south row of lamps.

Curve 5 is plotted from values of illumination calculated at the several stations in the manner described for curve 1, Fig. 14. In this case the total ceiling area is 5,476 sq. ft. and the equivalent flux per sq. ft. is therefore 8.4 lumens with an equivalent specific intensity of 2.7 foot-candles. Allowance should be made in comparing these curves for the fact that the gallery fixtures were lighted during the test plotted in curves 1 and 2. Their effect on the floor of the hall however, is not very great—0.5 foot-candles at the most near stations B and F. Curve 6 is plotted from calculations for comparison with curve 4. In comparing curves 1 and 5 it should be noted that in the case of curve 1 the coffer transoms cut off the direct light on the floor from any one sash about 37 feet from the projection on the floor of the sash center.

On a basis of 40 per cent. efficiency with clean sashes, the loss by accumulated dirt is found as follows: Measured—I = 2.86 at station A. Deducting 0.46 for illumination due to gallery lamps and allowing a reflection coefficient of 20 per cent. gives I = 2.00. Total generated flux per sash = 8 lamps × 300 lumens = 2,400 lumens. Net lumens per sq. ft. glass on a basis of 40 per cent. efficiency and 10 per cent. loss by mullions, etc.

(giving a net efficiency of 36 per cent.) = 34 lumens. Apparent specific intensity per sq. ft. glass = 10.8. Total glass area = 1,100 sq. ft. Total area ceiling = 5,476 sq. ft. Equivalent specific intensity per sq. ft. ceiling = 2.2. Calculated I at station A = 5.60. The apparent value of i per sq. ft. of ceiling that would produce a value of I = 2.00 is 1.00. The apparent equivalent flux per sq. ft. of ceiling is, therefore, 3.14 lumens. The total apparent flux is then 3.14 lumens × 5,476 sq. ft. = 17,200 lumens. The total generated flux is 117,600 lumens. The

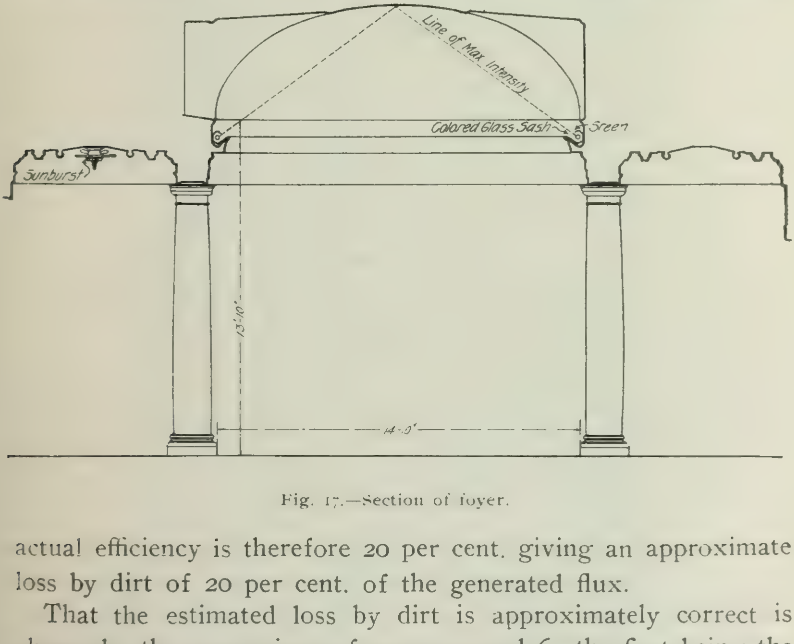


Fig. 17.—Section of foyer.

actual efficiency is therefore 20 per cent. giving an approximate loss by dirt of 20 per cent. of the generated flux.

That the estimated loss by dirt is approximately correct is shown by the comparison of curves 4 and 6; the first being the curve obtained, as above explained, by readings from the central sash alone when clean, and the second being plotted from calculations using the following constants: Generated flux = 3,648 lumens; sq. ft. glass = 22.5 net; flux per sq. ft. = 164 lumens; net flux per sq. ft glass at 40 per cent. efficiency and 10 per cent. loss by mullions = 60 lumens; i = 20 candles.

LIGHTING OF THE ENTRANCE FOYER.

It was originally proposed that the lighting of the vaulted foyer

ceiling should be accomplished by completely concealed light sources. The design provided a projecting cornice on each side and end and a cove was built in the upper side of this cornice of sufficient size to receive a trough reflector using silvered Belgian rippled glass as a reflecting medium. No reflector was provided in the cornice under the tympanii forming the ends of the vault. There are 60 25-watt, 112-volt, clear bulb tungsten lamps with axis horizontal in each reflector.

The reflector was designed to so distribute the flux that the greatest intensity would be in the direction of the apex of the vault and would fall off gradually toward the spring of the vault.

A dense opal glass screen was provided for the entire length of each reflector arranged so that it could be swung about the side attached to the reflector casing. After the reflector was installed the screen was adjusted so as to intercept any direct light on the plaster work immediately above the cornice. Any irregularities were removed by tinting the screen. The open face of the reflector was then glazed with clear glass to keep out dust.

The effect of the very careful work with this reflector is a good example of what was meant above when I spoke of the relation of light to architecture. The illuminating result was exactly that intended. The brightest part of the vault was the part farthest from the reflector, the darkest part that just over the reflector. A moulding just above the reflector parallel to the cornice consisting of an ogee below painted blue and a fillet above painted red was less brightly illuminated on the round of the ogee than was the perpendicular plaster surface one foot above. Furthermore, the uninitiated could not tell where the light came from. The ceiling was luminous, and that was all. But the aesthetic result was that the vault appeared flat, the cornice receded and became apparently a decorated spring band in the plane of the spandrils of the longitudinal window arches. The architecture was ruined.

The work was begun over again, and, as luck would have it, when the reflector was turned over bodily on its axis through a few degrees, the ceiling became evenly illuminated from the back of the cove to the apex of the vault; a little further, and the

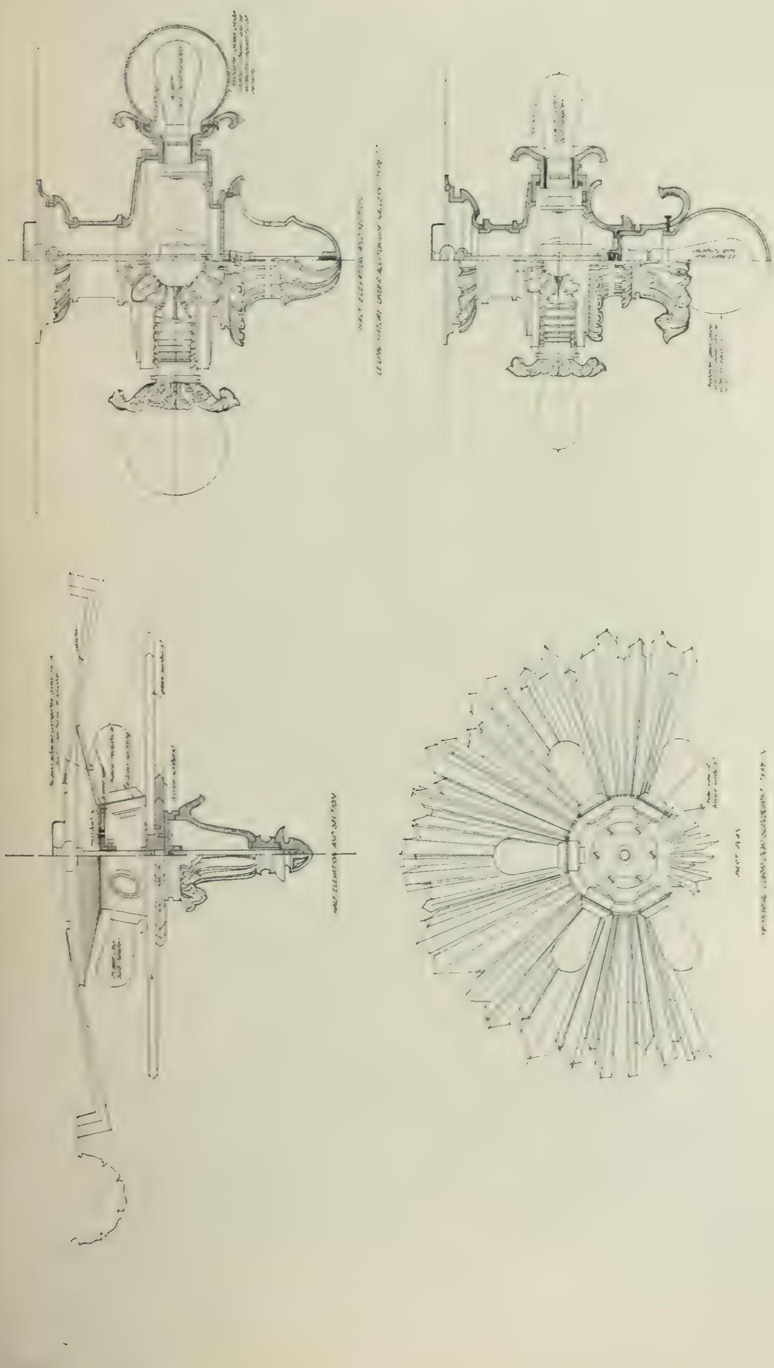


Fig. 18.—Fixtures, including one with sunburst.

brightest part was just over the cove. The cornice at once acquired its full value, and the vault became hollow. But still the lighting was too smooth—the foyer had lost some of its depth. To remedy this the reflector glazing was replaced with colored glass—flashed ruby being used under the spring of each of the longitudinal arches, and burnt amber between. The result of this treatment was literally to paint the vault with light. It is an extraordinary fact that the use of colored light to tint surfaces in architectural compositions has never been developed. Here, indeed, is a new theme in illumination, and one that has unlimited possibilities, if studied intelligently. Furthermore the use of grilles or decorative silhouettes interposed between the light source and the surfaces to be lighted so as to cast shadow arrangements can often be employed with telling effect. In this foyer there is such a result in its simplest form where the fan shaped darker ruby areas on the arch spandrils melt into the rosy amber areas of the main vault.

The photograph shown in Fig. 1 was taken before the colored glass had been installed, or the ruby color would have shown up in the plate as shadows.

The readings plotted in curves 1 and 2, Fig. 14, were taken with the final arrangement, and the screen of the luximeter looking like a poussé-cafè. The readings plotted in curves 3 and 4 were taken without the color screens and with the sunburst fixtures behind the columns and in the corridors lighted. Curve 5 is plotted from calculations assuming that the vault is evenly illuminated by the reflector so as to produce a constant normal reflected specific intensity over the vault surface of 1.00 foot-candles. It will be recalled that in the papers on "Finite Surface Sources," the author drew attention to the fact that no matter what the shape of the luminous source, provided its aperture is in a plane and the flux emitted per unit area is constant and distributed according to the cosine law, it may be treated as a plane source having the area of its aperture and a flux per unit area the same as that of the real source. This relation reduces the calculations of the illumination at any point due to this semi-cylindrical surface with semi-circular ends to the calculations for a rectangular source in the plane of the spring line of the vault.

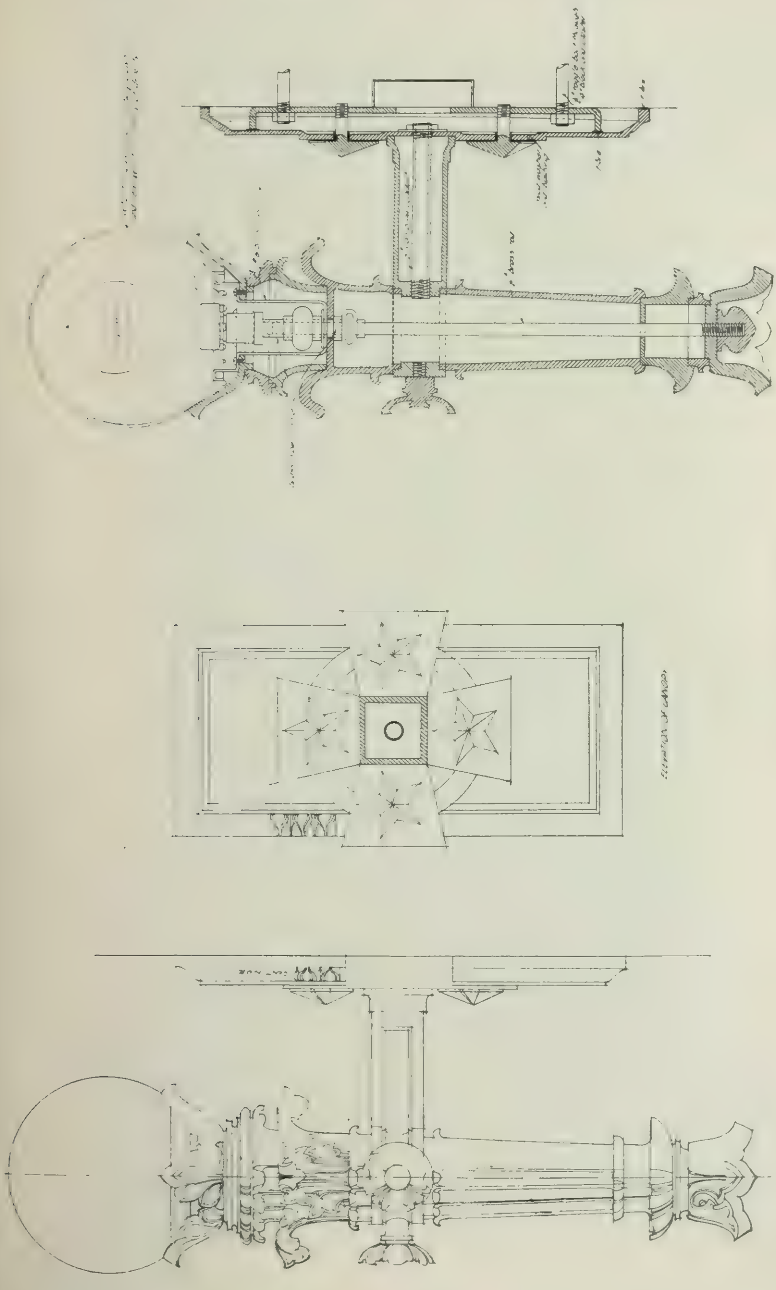


Fig. 19.—Post room brackets.

LIGHTING OF THE MEMORIAL CORRIDOR.

The memorial corridor is divided into ten-foot bays with recesses for memorials and emblems. The ceiling of each bay forms a richly ornamented and highly colored coffer into the top of which is worked a gold-leafed sunburst three feet in diameter. Directly below the central part of this sunburst is a circular silvered rippled Belgian glass reflector in the form of a truncated cone. Below this is a spinning supporting radially seven 25-watt, clear-bulb, tungsten lamps screened by a cast glass sunburst. The glass sunburst is supported by a bit of leaf work in bronze. See fixture type N. Fig. 18. An illumination curve for this corridor is plotted in Fig. 14.

FIXTURES.

All of the principal rooms and the exterior of the entrances are lighted either wholly or in part by more or less emblematic fixtures done in cast bronze. The drawings for some of these fixtures prepared by the writer from the architect's sketches are reproduced in Figs. 18 and 19. The details of design were however considerably modified in the models prepared by Mr. Charles Keck under the architects directions. The glassware in general consists of alabaster glass balls which prevent any appearance of images of the illuminants. The absorbtion is about 0.45, but, on the other hand, the intrinsic brilliancy of the glass surface is low and the diffusion is so perfect that the physiological efficiency of the illumination is very high. The minor rooms are lighted with simple spun brass fixtures equipped with opal reflectors.

ACKNOWLEDGMENTS.

The author desires to acknowledge his indebtedness, first, of course, to Messrs. Palmer and Hornbostel, the architects, for "leave to print," second, to Mr. Henry Hornbostel, to whom he largely owes whatever ideas he may have on the subject of illumination, for careful proof reading and for criticisms of this paper; third, to the Hon. J. G. Chalfant, county engineer, whose appreciativeness and good will did much to expidite matters, fourth, to the Iron City Engineering Co., of Pittsburgh, the contractors for the installation, whose efforts, interest and care

have contributed largely to its success. To Mr. W. D'A. Ryan, the writer owes thanks for checking results and for excellent criticism of the engineering features of the designs, and to Mr. D. L. Wright, representative at the building for Allegheny County, for untiring efforts in arousing public interest and for much friendly assistance.

The test readings were made by Messrs H. V. Allen and C. J. Mundo using the Ryan luximeter. The remarkable photographs of the interiors taken by artificial light are the work of Mr. B. H. Norris.

DISCUSSION.

Mr. Albert Jackson Marshall:—It is decidedly refreshing to have a paper presented before our Society that while dealing, in a measure, with the purely physical side of the problem yet treats so intelligently with other very important phases of illuminating engineering. Papers dealing with architectural problems are rare and very welcome. The Illuminating Engineering Society has unquestionably done a vast amount of good, on account of its research work and investigations along the utilitarian sides of the work. The effect of its efforts, however, are shown for the most part in unimportant installations, which condition is largely due to the fact that the so-called illuminating engineer has caused the architect, who has in charge the important installations, to feel that he had little or no regard for anything but so many watts per square foot, which would produce a given foot-candle intensity of illumination. Not only has the illuminating engineer caused this feeling to prevail, but in many instances he has most violently and ofttimes most unintelligently criticized the architect for what he, the engineer, considers to be horrible examples. The architect does not know perhaps as much about the purely physical side of the work as the engineer, but on the other hand the engineer does not understand "effects" as does the architect. It has been my experience that when the architect is approached in a manner which indicates a desire to coöperate, rather than to dictate, it is possible to get together on a working basis and create effects with efficient radiators and accessories which permit of economic maintenance.

The author has afforded a very good example of what can be accomplished with intelligent coöperation with the architect. It is perhaps true that the installation of the Allegheny County Soldiers' Memorial is the most unique scheme ever employed in a building, involving not only the obtaining of predetermined effects as conceived by the architect but the getting of these effects through the agency of mathematics and physics.

In a certain paragraph the author says: "It is of course only in comparatively few instances that the use of colored light in the design can be attempted but there are several interiors, notably in theatres, and other similar auditoriums where some such treatment would have been desirable. Not less daring did this idea seem to the writer when *suggested by the architects* than the then proposed architectural treatment of the principal rooms in the Memorial. The author is free to confess that he long doubted the possibility of achieving the results desired and believed that the effect would be decidedly disappointing. However, Mr. Hornbostel's enthusiasm and his undoubted genius eventually embued the writer with some of the same faith, and the result fully confirms the architect's emphatic belief in the beauty of his conception."

The point in this paragraph to which I particularly wish to direct attention is that the idea was suggested by the architect. Those who have believed that the architect was incapable of suggesting lighting schemes, which would be considered good, as judged by standards as set up by some illuminating engineers would doubtlessly be quite surprised in knowing that this wonderful lighting installation was not only conceived by the architect, but it was the architect who in having faith in his ideas urged the engineer to push them to a successful conclusion. This in no sense detracts from the excellent work of the engineer, but shows clearly that the architect is not only in a position to authorize the carrying out of lighting schemes in the buildings which he is designing, something only in rare instances that the engineer is capable of doing, but he also has the ability to conceive effects which are, to a high degree, original and satisfying.

On many occasions, before this Society and elsewhere I have urged that those interested in furthering the intelligent use of

artificial light obtain the hearty coöperation of the architects. This coöperation is possible to obtain provided the engineer will knock out of himself some of the exaggerated ideas that he has of his ability with a corresponding little regard for the ability of the architect. The engineer should realize that after all is said and done, when a lighting system has been designed in the majority of cases, it must be employed in the building which the architect has designed and unless such scheme is acceptable to the architect it will not be employed, at least not in the manner in which the engineer has designed it. When the architect and the engineer work with a clear understanding of the part that each plays, or should play, in the work, the lighting schemes that they employ in buildings are at once a credit to the architect and to the engineer.

The author comments on the promiscuous use of tungsten lamps. The tungsten lamp, like every other good thing, is suitable for certain work, but it is not a panacea for all lighting ills. Judging by its use, however, one would be inclined to feel that those responsible for such usage would consider it in the panacea class. An effort has been made by some people to popularize the use of the tungsten lamp in the home. Some mere men have gotten together and have been so foolish as to think that they were in a position to dictate as regards the lighting of the home, apparently ignoring the true master of the case, which is the woman. Most men, especially those who reckon pleasure in dollars and cents and likewise those who, in the designing of lighting installations can see nothing but lumens and foot-candles, fail to appreciate that while the cold, hard, light of the tungsten lamp is permissible in certain rooms in the home, yet it is practically impossible to obtain from untreated radiators the mellow effects produced by treated radiators or those approaching the kerosene and candle flames or by the very good old standby of recent times, the carbon filament incandescent electric lamp.

There is a tendency to divorce absolutely from all incandescent electric lamps except those of the tungsten type. Perhaps after we realize that the desired results can not thus be obtained we may profit by our experience and hereafter treat with lighting installations in a sane, logical and intelligent manner.

Mr. Henry Hornbostel:—It is very curious to realize that il-

lumination of buildings nowadays may be, and often should be different from the illumination of buildings, say 30 or 40 years ago. Then it was a question of getting light. To-day it is not so much a question of merely getting light as it is a question of getting a charming, fascinating, pretty and useful light. Yet it is very curious fact that the old tradition, or the spirit of imitation, or the spirit of custom, still shows itself in the work of a great number of our illuminating engineers and architects. The old-fashioned idea still clings to us, and the new conception of things is taken up in a rather hesitating way.

Illumination to-day is like painting; it is like decorating a wall. Some time ago walls were so constructed as to make them warm. To-day the walls are so decorated to make them beautiful. The same tendency is or should be true of illumination. To-day one should illuminate his room so as to make it charming, so that the complexion looks flattering, especially in the case of rooms used for festive purposes. It is noteworthy that in the homes the little standing lamp, with a little shade over it is coming more and more into prominence. The reason is that this type of lighting device makes a person look best. It makes everybody in the home look pleasant and charming. A person does not care whether it is or is not efficient, or whether its radiance is very intense or not, or widely distributed, for if he wants to read a book he goes to the little lamp and reads there. Thus, the tendency to flood everything with light that showed itself shortly after the cheap use of electric light was discovered, so that every interior was a glare with unnecessary light that made one decidedly uncomfortable when he first entered from the dark streets, has been gradually overcome by common sense and good taste. Such over-lighted interiors can never be made to feel homelike. They have, in fact, a curious psychological effect —they produce a nervous excitement that makes a person desire to screech and dance and amuse himself in a way that will release a maximum of nervous energy. Most interiors should, in fact appear homelike, and must be lighted so that they will so appear. On the other hand the interior that is to be used for amusement must be considered solely from the point of view of the use to which it will be put and lighted appropriately. One does not want to listen to fine music in a gay ballroom, nor does he

feel like dancing in a church. Economy from the viewpoint of illumination can have but a very minor place in the study of such cases. The ballroom, for instance, is a place where people go to have a good time. It is a luxury and no place for the practice of economy; it must be lighted in the best way so as to make it cheerful, and bright and joyous, and efficiency as an illuminator must be measured by such results and not at all on the basis of cost per night to operate. The value of the installation is then solely in the fact that everybody enjoys dancing in that room. In fact, the proprietor simply says, "Go on and spend as much as you want, as long as I can get customers." That is modern economy. That is the spirit of the times.

But brilliancy is not the only scale to play upon. There is also the use of colored lights to be considered, and here is a field that possesses almost unlimited possibilities. One can do with colored lights almost anything he wishes. They may be used as the painter uses his tones and tints in decorating an interior. A person can decorate a room in colored lights and make it ridiculous, and again he can make it dignified. He can use colored lights in the scheme of decoration so as to accent a religious note or he can do exactly the opposite. It is like working different tones into a painting, and in fact he is doing far more than merely lighting the room. He is producing effects that will be pleasant at night time and may add decidedly to its charm and beauty.

Now this is something entirely different from anything that could ever be done with the old candle or gas lamp. It is entirely different from the old idea of making light merely to enable one to see and walk around. It is an absolutely new conception in lighting, and the tradition and custom which still keeps one thinking only of the old methods of lighting, prevent progress. In fact there is available an essentially and purely modern artistic medium—artificial light.

There is a little example of the effect of habit and custom which is perfectly delightful, and which I notice every once in a while, and always bring up as an example. When ferry boats with the paddle wheel along the side were first introduced, the paddle wheel box was emphasized by means of a sort of colored sunburst or fan. Later the propellor drove out the

side wheeler but up to very recently propellor boats still went to and fro across the North and East Rivers with the sunburst or fan, or some new sort of decoration in the middle, still suggesting the presence of the paddle, and it took almost three years to get away from that curious decoration of the paddle wheel box, and to make ferry boats like the side of a car. This example shows the spirit of imitation and the restriction of custom prevents the mass at large from really making rapid progress.

The fact that there is now available a medium which is not the medium of thirty or forty years ago, but an entirely new one, is the foundation on which to build. If the medium is not used correctly and carefully, one can destroy what he is trying to do; it requires knowledge, experience, restraint, and careful study to get just the correct results. I remember distinctly that when I suggested this ceiling to Mr. Jones, I said, "It is going to be just like the advertising signs on Broadway. Something that is amusing, playfully ridiculous, and laughable. These signs don't mean anything except advertising, but they do that well, and our ceiling shall do the same for Pittsburgh." Well if the ceiling had produced the same effect as a luminous sign, we would have failed wretchedly, and that was the great danger of which we were always afraid. But finally when the ceiling was finished, we felt that the only way it could be judged was by the audience, and not by ourselves. So we were naturally anxious to see the way the public would take it and how people would act, when the building was opened for use. The greatest satisfaction for me in the result was in being present at three or four entertainments and at the dedication of the building, and in noticing the serious behavior of the audience. Nobody laughed. Nobody smiled. All acted as though they felt themselves to be in the presence of something glorious.

Mr. G. W. Jacoby:—As an architect I want to congratulate Mr. Hornbostel on the marvelous effect he has obtained in this building, which, I think, points the way toward a new field for the combined efforts of the illuminating engineer and the architect. I do not know that the architect has ever before even thought of attempting anything in this line. I want to express the appreciation the architects throughout the country must feel

of the work that Mr. Hornbostel and Mr. Jones have done in achieving this greatest of successes.

Mr. G. H. Stickney:—Recently, I had the pleasure of seeing the illumination which has been described, under conditions that were rather interesting. I was attending a convention of engineers connected with steel mills. One of the features of the convention was a visit to the building to see the illumination. We witnessed the artistic combinations of light one after another in almost, as we might say, a symphony. Being interested particularly in this installation, I took pains to watch the men and see what effect it would have and what they thought of it. It was observed that they would always speak in whispers or low tones. It seemed to bring out the feeling of reverence; there was a sort of a hush. In another way there seemed to be a feeling as if it were something beyond them. They did not quite understand; they did not know just what it meant; they had not become accustomed to it or the thought of it. I do not think anybody questioned for a minute, but what it was a masterpiece which they were trying to study and trying to understand and to interpret.

And looking at the undertaking again from another view, this installation is remarkably interesting in that it brings out so much of originality. A daring thing has been undertaken and is being made a splendid and beautiful success.

Mr. Edgar Ellinger:—One point has been brought very forcibly to my attention, namely the relation between the original imaginary effect and the actual results produced. In conceiving this wonderful illumination there was anticipated an effect that might not exactly harmonize with the imposing structure; it was thought that the result would be too striking, intense and startling, but instead actual conditions reveal complete harmony and an inspiring illumination. The paper clearly shows that between the time of the original thought—its planning and working out—and the actual realization, there was a natural toning down which brought the result well within the range of good practice. It is also a marked lesson to show that the imagination can and should be drawn upon almost to its fullest extent in planning new illuminating effects.

Mr. J. B. Taylor:—What is the general quality of the light

when all the different lamps are turned on; the pink of the nitrogen tubes, the blues and green of the mercury lamps, the yellow of the flaming arcs and the more or less white of the incandescent lamps, are all added together? I am interested to know what the resultant color is, and whether any test has been made to determine it.

What Mr. Marshall said about some applications of the tungsten lamp is quite true. The polite evening light seems properly more of a yellow color than a white. While much is said about the daylight quality of certain lamps there is little question but that the yellow light is more pleasant for evening. I recollect very well a case where tungsten lamps had been put in on account of high efficiency, but a few weeks later they had been dipped in something yellow, while a few lamps in another room had been dipped in something pink. A proper question for investigation is whether a tungsten lamp made yellow by screening is more economical than a carbon lamp, which is inherently more yellow.

In the building described the open flaming arc lamps are operated on alternating current, presumably because direct current is not available. If the hall is to be used for music or speaking, the sound produced incidental to the light seems unfortunate as it is disconcerting to a speaker and can not be harmonious with music in all keys.

Mr. Jones:—The sound of the flaming arc lamps is not an unfortunate feature of the Auditorium lighting. It is a distinct and pleasant musical note that is emitted and not a noise; furthermore, should this note prove distressing on the occasion of a concert, the lamps may be put out without affecting the intensity of the illumination. In fact, the illumination of this room with all lamps lighted is entirely too intense when a concert is in progress and detracts from all but the most joyous and triumphant character of musical composition. The psychological effect of light is exceedingly interesting. Numerous lighting effects can be obtained in this room quite appropriate to a wide variation in musical moods, and may be employed to intensify the receptive mood of the listener, in much the same way that Wagner has employed lighting effects in his music dramas.

The question has been raised as to the color effects of the il-

lumination. Unfortunately I was unable to procure a colorimeter for use during tests, particularly as the results obtained by such an instrument would have been of great general interest.

The general tone of the ceiling with all lamps in use is a little too monotonous in the yellow. This defect can, however be readily corrected by the use of colored glasses superimposed on various areas of the sashes. In this connection, a rather interesting accident occurred. One of the workmen left a sheet of very thin blue print paper over one of the sashes illuminated by the flaming arc lamps. There resulted a light from this sash of an exquisite sea green, and we propose to duplicate this effect with blue color screens. A further variation can be obtained by varying the composition of the flame arc electrodes, and by varying the color of the diffusing screens which we propose to use in connection with these lamps.

The general effect of the color of the light mixtures on the painted surfaces of the room is remarkable. The general wall surfaces become a light pinkish gray of a very pleasing tone. The red lead panel surfaces become almost orange. The blues become greenish, and the yellows are richened to an extraordinary extent. Thus, by night, all the various pure tints are brought together by mixture with yellow, and, as the plaster surfaces become darkened with soot a further deepening of the general effect ensues.

Mr. Ellinger has spoken of the interesting fact that the results fell far short of our expectations, and as has drawn the conclusion that one need never be afraid of overstepping the mark, since the embodiment of our ideals must always fall far short of the intent of such ideals. This is, of course always true of worthy ideals. But, as Mr. Hornbostel has pointed out, in this case we had anticipated an effect, more or less bizarre in character, so that the actual result is another fortunate accident. This result is probably only another indication of the very small margin between the beautiful and the ugly, between the sublime and the rediculous. By our inability to overdo we have struck a true note.

Yet this must not be taken as an argument against future similar attempts. Our original argument was that, since it seemed quite hopeless to produce a beautiful effect due to the

apparent limitations of our materials, we could at least produce an unprecedented display. Now that we know just how our limitations effect the results it will be a simple matter to produce a result still more beautiful than that obtained at the Soldiers' Memorial.

Mr. Hornbostel:—The effect of the low note in the auditorium due to the singing of the arcs is decidedly agreeable; it has led to an experiment we are going to try. We intend to install two lanterns at The State Education Building in Albany, and those two lanterns will be arranged to sing. The sound emitted by each lantern will be a chord, and the two chords will be in harmony. I think that in spite of the fact that the idea may at first seem ridiculous, or rather funny, and it might make people laugh, yet those who do hear the low tone in front of that great building will be agreeably surprised. There is no reason why, even in the home there should not be a pleasant sound produced by an electric lamp of some form or other. There would be no reason why, for instance, in front of a huge theatre or opera house the electric lamps should not give forth a musical note or harmony which could be turned off as the performance started, or turned on again as the audience left. There would be nothing essentially curious about such an effect. There would be nothing funny about it. There would be nothing even experimental. It is perfectly possible, and we are going to try it.

While the sound in the Auditorium was an accident, it was a happy accident, and besides, was not bad at all. Furthermore, the idea that there is enough light in the ceiling so that some of it can be turned off, and still be enough light to give a sense of luxuriousness that is not a sense of extravagance, and that is just what we want.

In regard to the dirt on the sashes, that dirt was not such bad dirt at all. Of course, every once in a while some piece or other of building material may cause a little spot. Yet these can very easily be removed. On the other hand, we found that interesting effects could be obtained by cleaning only some of the little panes in each sash, and in fact there is no reason why these little panes might not vary in color as well as in brightness. Although these little variations reduce the parabolic curves which Mr.

Jones thinks so much about into waves, it results in a very pleasant effect.

As to the color scheme, let me accent the statement that there is not a bit of black in the entire building. There is no brown and no sepia. The colors are absolutely pure. The blue is pure cobalt blue; the red, the purest red lead we could find; the yellow, pure chrome. The intention was to omit the harmonizing value of black, which, in the form of jet so frequently used by the Chinese to harmonize their vari-colored prints, pictures and tapestries. If we had put the black in at the beginning which would have been an easy thing to do, at the end of a year all the colors would have been black.

Mr. Jones:—The prevention of the accumulation of dirt on the colored surfaces beyond a desirable amount is a simple matter. The Auditorium is sealed and obtains its air entirely through an extensive ventilating system. The air which is drawn from the outside is now filtered through cheese cloth so as to remove only the larger particles. So soon as the desired tone has been obtained air washers will be installed and the air supplied to the auditorium will then be absolutely clean.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VI. FEBRUARY, 1911. NO. 2

MINUTES OF COUNCIL MEETING.

FEBRUARY 10, 1911.

The first meeting of the council under the 1911 administration was held in New York on February 10. In attendance were A. E. Kennelly, president; V. R. Lansingh, treasurer; L. B. Marks, W. H. Gartley, George Ross Green, A. S. McAllister, Herbert E. Ives, E. P. Hyde, E. B. Rosa, Theodore H. Piser, J. T. Maxwell and Preston S. Millar, general secretary.

Inasmuch as the minutes of the previous council meeting had been mailed to each member of the council, the reading of the minutes was dispensed with, and the council proceeded to a consideration of the general secretary's report. This showed that the membership had been 1878 on Jan. 13th. During the intervening month, 18 resignations, 14 applications and four requests for reinstatement had been received. Affirmative action on all of these would make the membership to date 1478, which is 42 per cent. larger than that enrolled on the corresponding date last year.

Mr. L. B. Marks, chairman of the finance committee, presented a report of the finances of the society for the year 1910 supplementing the committee's annual report which appears elsewhere in this issue. His committee had observed that stricter economy in expenses of 1911 could be effected.

With the report Mr. Marks also presented a list of the January vouchers, amounting to $1,248.93, which the finance committee approved for payment. The council resolved that the recommendations contained in the finance committee's report should be referred to the next finance committee, and authorized the payment of the vouchers as listed.

Two other resolutions relating to the society's expenses were adopted. The first was that the management of sections be advised that it is not the policy of the society to pay any ex-

penses of authors or lecturers who present papers or lectures before the section meetings. The second was to the effect that the management of each section submit a budget of section expenses for 1911.

President Kennelly then announced his appointments for the finance and executive committees, which appointments were approved by the council.

Finance Committee.—L. B. Marks, chairman, A. A. Pope, A. S. McAllister.

Executive Committee.—A. E. Kennelly, *ex-officio,* P. S. Millar, *ex-officio,* V. R. Lansingh, *ex-officio,* L. B. Marks, A. S. McAllister.

Other committee appointments of the president are to be submitted to the executive committee which the Council empowered to approve.

After considerable discussion it was decided to appoint a new membership committee which will consist of the chairman of section membership committees and three other members to be appointed by the president. Sections which have not already appointed membership committees will be requested to do so.

After consideration of the advisability of appointing a research committee, an informal vote indicated that the council was unanimously in favor of appointing such a committee in the near future.

Two changes in the By-Laws were proposed and received a first and favorable hearing.

It is proposed to revise Art. VIII, Section 2, making the first sentence read:

"Regular meetings of the council shall be held once each month, except during the months of July, August and September."

It was proposed also to change Art. III, Section 6 of the By-Laws to read as follows:

"The entrance fee shall be $2.50, payable on admission to the society."

In this connection the council resolved to waive the initiation fee until July 1, 1911, and to impose it beginning with that date.

The resignation of Mr. F. N. Morton, a director, was accepted. Mr. George S. Barrows was appointed to fulfill Mr. Morton's unexpired term.

An invitation from the board of managers of the Chicago section to hold the next annual convention in Chicago was accepted, the date of the convention to be determined later.

Discussion of the matter of advertising in the TRANSACTIONS resulted in a resolution to make available for advertising purposes double the number of pages now devoted to advertising in each issue of the TRANSACTIONS. The advertising committee was requested to endeavor to secure a correspondingly increased amount of advertising.

SECTION MEETINGS.

NEW YORK SECTION.

The regular monthly meeting of the New York Section was held in the "Dungeon of Castle Cave," on Thursday evening, February 9th at 8:15, where an informal dinner had been served to 65 members and guests beginning at 6:00. There was no formal paper, but a general discussion on "Light and Architecture" was lead by Mr. Henry M. Hornbostel of the architectural firm of Palmer & Hornbostel. The discussion was participated in by chairman A. H. Elliott, Secretary A. J. Marshall and Messrs. Donn Barber, J. Holden, S. F. Vohis, Bassett Jones, V. R. Lansingh and D. McF. Moore.

The March meeting of the section will be held at the Gimbel store, Sixth Ave. and Thirty-third Street, where a paper descriptive of the lighting installation of the store will be presented by Messrs. C. L. Law and A. J. Marshall.

At the April meeting Mr. Bassett Jones, Jr., will read a paper entitled, "Polar Curves of Finite Surface Sources," and a paper by Dr. J. C. Pole entitled, "The Photometry of Mercury-Vapor Lamps," will be presented for discussion.

PHILADELPHIA SECTION.

The Philadelphia Section held a meeting at 8:00 P. M. on February 17th, at which an illustrated lecture on "Artificial versus Sunlight for the Making of Moving Picture Films," was delivered by Mr. Edmund L. Simons. The meeting was preceded by a dinner served at Green's Hotel at 6:00 P. M.

CHICAGO SECTION.

The Chicago Section held its regular monthly meeting at noon on February 16th at the Great Northern Hotel, Chicago. As usual a luncheon was served before the meeting proper. The topic for general discussion was "Illumination Problems in the Smaller Cities," the speakers being Messrs. J. R. Cravath, C. A. Luther, A. L. Eustice, C. A. Howe and J. G. Learned. Vice-President H. E. Ives and General Secretary P. S. Millar spoke of the work of the Society, its policy and possibilities for still greater activities and brought the official announcement of the selection of Chicago as the place for holding the next annual convention.

At the March meeting a paper will be presented by Mr. James R. Cravath on "The Illumination of Small Rooms."

GENERAL SECRETARY'S REPORT TO THE COUNCIL FOR 1910.

To the Council:

Nineteen hundred and ten, the fifth year of the Illuminating Engineering Society's organization was notable in a number of respects. At no time previously has illuminating engineering as a specialty commanded as much respect. At no previous time was the Society accorded as high consideration by members of affiliated societies and by the public at large. During no previous year has the membership evinced as marked a desire to promote the interests of the society.

One of the notable features of the society's record during 1910 is the large increase in membership, as shown in the following table:

MEMBERSHIP CHANGE.

Membership at beginning of year	1045
Elected to membership during year	650
Resigned	76[1]
Dropped for non-payment of dues	82
Deceased	7
Membership, December 31, 1910	1530

[1] Including a number of resignations presented during 1909 but acted upon during 1910.

INCREASE IN MEMBERSHIP.

Of the 650 accessions to membership it is estimated that more than 500 were the direct result of the campaign conducted by our membership committee. Starting with a selected list of names of men who were thought likely to be interested in the work of the Society, this Committee directed to each a series of carefully worded communications calculated to advise concerning the nature of the Society and the work which it is doing, and inviting the recipient of the communication to become indentified with the movement. For the cost of this campaign, covered by appropriation for the purpose by the Council, the Society has been nearly reimbursed through the payment of first dues of new members.

DEFECTIONS.

During 1909 the council dropped from the society's rolls 98 members who had failed to pay dues. The dropping of 82 members similarly delinquent during the past year, as well as the rather large resignation list, serve to direct attention to the fact that a very considerable proportion of those who join the society fail to find in the meetings, or in the TRANSACTIONS of the society, enough that they consider of direct personal value to warrant continuation of membership. This is not the society's fault, but results rather from heedless action of individuals in joining an organization when insufficiently informed concerning its purposes and activities.

DEATHS.

Five members have been taken from our ranks by death:

Mr. H. J. Buddy.
Mr. T. O. Horton.
Mr. A. G. Pickens.
Mr. C. J. Toerring.

DIVERSITY UNCHANGED.

While the number of members has increased largely during the year, the society remains unique in the diversity of its membership and in the number of professions and industries represented. The accompanying analysis of the membership as of

TABLE I.—MEMBERSHIP CLASSIFICATION. DEC. 31, 1910.

Industry or profession with which connected	Total members	Total per cent.	Total of groups	
Electric Lighting—				
Central stations	322	21.0		
Industry in general	223	14.5		
Lamp manufacturers	168	11.0		
Apparatus manufacturers	142	9.3		
Consulting engineers	47	3.1		
Contractors	31	2.0		
			933	61.0
Gas Lighting—				
Gas companies	245	16.0		
Lamp manufacturers	27	1.8		
Industry in general	38	2.5		
Acetylene gas and lamp manufacturers	3	0.2		
			313	20.5
Gas and Electric Lighting	13	0.8		
			13	0.8
Illumination in General—				
Globe and reflector manufacturers	78	5.1		
Fixture manufacturers	5	0.3		
Consulting illuminating engineers	4	0.3		
			87	5.7
Miscellaneous—				
Pedagogic	72	4.7		
Technical journals	18	1.2		
Research and testing laboratories	23	1.5		
Architects	13	0.8		
Scattering	13	0.9		
Unclassified	45	2.9		
	1530	100.0	184	12.0

TABLE II.—CHARACTER OF PAPERS INCLUDED IN FIRST FIVE VOLUMES OF TRANSACTIONS OF ILLUMINATING ENGINEERING SOCIETY.

Of more particular value to those interested in

Papers dealing with	Acetylene lighting	Architecture	Calculations	Daylight	Electric lighting	Fixtures	Gas lighting	Illuminating engineering	Illuminating oils	Pedagogy	Photometry	Physics	Practical research	Standards and units	Street lighting	Vision
Acetylene lighting	2	—	—			—	—	—	—	—	—	—	—	—	—	—
Architecture	—	6	—	—	—	—	—	6	—	—	—	—	—	—	—	—
Calculations	—	—	14	—		—	—	7	—		—	—	—	1	—	—
Daylight		—	—	1	—	—	—	1	—	—	—		—		—	—
Electric lighting	—	2	—	—	16	—	1	5	—	—	2	1	—	—	2	—
Fixtures	—	—	—	—	—	9	1	5	—	—	—	—	—	—	—	—
Gas lighting	—	—	—	—	—	—	16	8	—	—	—	—	—	1	—	—
Illuminating Engineering	—	1	2	1	3	—	1	52	—	—	4	2	1	—	—	1
Illuminating oils	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—
Pedagogy	—	—		—			—	2	—	2	—	—	—			—
Photometry		—			1	—	3	11	—	—	16	1			—	
Physics				—	1		3	2			2	8				1
Practical research				2	1			4	—	—	1	1	7		—	
Standards and units	—	—	—			—	1	1	—		2			9	—	
Street lighting				—	4	1	4	—		—	1			—	15	
Vision		—	—	—		—	—	2		—	1	1	—	—		12
Totals	2	9	16	4	26	10	30	106	1	2	30	14	8	11	17	14

Dec. 31, 1910, shows the number of members connected with each of a number of industries or professions.[1] That but little change in the distribution of membership has taken place in the last two years is shown by comparison between this analysis and a similar one made two years ago.[2]

CHARACTER OF PAPERS.

To afford an idea of the scope of the society's deliberations, an analysis of the papers included in the first five volumes of the TRANSACTIONS has been prepared, and is appended. The subjects treated in the papers are listed and the number of papers devoted to each subject is shown. In addition, the table is made to indicate the number of papers discussing any one subject which are of more particular value to those interested in correlated subjects. It is to be expected that most of the papers presented will be of general interest to the membership at large, but in this analysis the effort is made to indicate the classes of membership who would find material of particular value or interest in the papers referred to. For example, there have been presented before the society, 14 papers dealing with calculations in the field of illumination. Each of these is of course of value to those who are interested in illumination calculations; seven, however, are believed to be of great value to practicing illuminating engineers and one is of interest in connection with standards and units. Again, there have been 52 papers dealing with matters involved in illuminating engineering practice. Each of these possesses of course interest to illuminating engineers. One, however, is of marked interest in connection with architecture, two in connection with calculations, one with daylight, three with electric lighting, one with gas lighting, four with photometry, two with physics, one with practical research and one with the study of vision.

[1] Due to obscurity of titles and various modes which the members have of expressing the nature of their occupations it is very difficult to compile information of this character and it is therefore not unlikely that this table is not altogether correct as to distribution of membership. However, it is undoubtedly accurate enough to afford a fair indication of the true distribution of membership.

[2] See TRANSACTIONS, Vol. IV, page 465.

Here we find the diversity in membership fairly well reflected in diversity of subjects discussed in the TRANSACTIONS. Indeed, the subject of illumination is so complicated, every question which arises has so many ramifications, there are so many different points of view from each of which new considerations arise, that it is only through a diversity of membership such as that indicated that the society can hope to cope with its problem.

It is believed that most of the members who have withdrawn from the society after a short connection have done so because they failed to find in the society that degree of attention to some particular phase of the subject which they had anticipated. Prospective members will find in the analysis of papers here presented, more or less of an earnest of the material which is likely to be embodied in the TRANSACTIONS in the near future. They should consider well if TRANSACTIONS of such a character will cater to their needs.

SECTION ACTIVITIES.

The sections of the society have continued the work of the previous year more or less along similar lines. No new sections have been added. A summary of section activities appears below:

	Chicago	New England	New York	Philadelphia	Totals
Technical meetings	10	8	9	8	35
Average attendance	45	25	65	85	
Papers contributed to TRANSACTIONS	1	5	16	5	27
Papers not reproduced in TRANSACTIONS	1	0	2	4	7
Lectures	3	1	0	0	4
Meetings given over to discussion	5	2	1	1	9

IMPORTANCE OF SECTIONS.

The constitution of the Illuminating Engineering Society gives to the sections a very considerable degree of autonomy, providing for a separate governing body, having one member who is also a member of the council and is one of the vice-presidents of the society. Except for the annual convention, the work of the society in the way of public meetings for the discussion of subjects pertaining to illumination is carried on exclusively by the sections. It is within the power of the sections to make or mar

the society. Their importance to the success of the society cannot be overstated.

CLOSER COÖRDINATION OF SECTIONS DESIRABLE.

The success attained by the sections has been varied, ranging from unqualified success to a condition verging upon failure. There has been in the society ever since its organization, some sentiment in favor of a closer coördination of the work of the sections and a closer bond with the central governing body. Many of the section officers themselves feel the need of something of this kind.

SECTIONS TOO ISOLATED.

In certain sections the vice-president has not been effective in connecting his section with the council. Very frequently section officers are unfamiliar with the traditions of the society, and without an active vice-president to keep them in touch with the council, act at variance with the policies of that body.

These and other conditions point to the need for an active committee on section development such as that appointed last year.

LECTURE COURSE.

A special feature of the year was the course of 36 lectures on illuminating engineering, delivered at Johns Hopkins University under the joint auspices of the university and this society. This lecture course was influential in giving illuminating engineering a status in the eyes of the public which it lacked, and it forms a splendidly balanced foundation for collegiate courses in illuminating engineering. A conception of President Hyde, it was carried to a successful consummation largely through his indefatigable efforts.

CONVENTION.

The annual convention held in Baltimore was successful both in attendance and spirit. Twelve papers were presented and discussed. The amount expended for entertainment was much less than in 1909, a gratifying economy which was effected without reducing the standard of pleasurable features which have been incidental to our conventions.

TRANSACTIONS.

The TRANSACTIONS of the Society are furnished to all members in good standing, in part return for dues paid. Our dues have not been increased nothwithstanding a greatly increased cost of issuing TRANSACTIONS, occasioned chiefly by their greater bulk.

A very gratifying demand for complete sets of TRANSACTIONS will probably make reprinting of early volumes advisable in the very near future.

The much needed index to all volumes of the TRANSACTIONS has been provided during the year.

COMMITTEES.

The Committee on Finance has exercised the usual oversight over the finances of the society, approving all bills for payment and approving all proposals looking toward expenditure not strictly routine in character. The committee has held monthly meetings and has devoted great care to the fulfilment of its functions.

The Committee on Papers has passed upon all papers to be included in the TRANSACTIONS, in addition to arranging for the papers programme at the annual convention. This committee has had some trying questions to decide in connection with the policy which should govern in the admission of material to the Transactions.

The Committee on Editing and Publication. The work of this committee has been done almost exclusively by the chairman whose duties are laborious to an extent which the general membership fails to appreciate and are rendered no less so by criticisms arising out of the fact that no editing policy can please all members.

The Committee on Nomenclature and Standards.—The work of this committee during the year has been confined very largely to that done through the sub-committee on photometric units, which rendered a preliminary report at the annual convention and is now engaged, under the mandate of the convention, in an attempt to secure concerted action by various societies at home

and abroad in the establishment of a uniform set of names, symbols and definitions.

The Committee on Lecture Course, consisting of the past-presidents of the society, with President Hyde as chairman, undertook and carried to successful completion the truly colossal task of the lecture course at Johns Hopkins University. The time and thought devoted by the members to this enterprise make the society and the cause in general further indebted to them.

The Committee on Section Development.—This committee did little effective work during the year, but proceeded far enough to develop the possibilities of the work which it was calculated to accomplish, and retires with the recommendation that a committee be appointed to complete the work.

The Committee on New Membership.—The effectiveness of the work of this committee is attested by the membership increase record previously mentioned.

The Committee on Advertising.—The advertising policy adopted by the council has not called for any extension of the advertising in the TRANSACTIONS. Consequently the activities of this committee have consisted in securing a continuation of existing advertising contracts, and in accounting work incidental to handling the contracts.

The Committee on Membership Division.—This committee was appointed by the president at the request of some of the members of the society to consider the advisability of a division of the membership on some basis. The committee submitted a report to the membership at the annual convention, recommending in effect that when the society felt a division to be a desirable thing, steps should be taken to effect a division. This report was accepted and the committee discharged.

The Committee on Progress, due to unavoidable circumstances, was not able to prepare a report for submission at the annual convention. If the committee is reappointed during the coming year, it is hoped that the first report on progress in illumination may be submitted at the 1911 annual convention.

Committee on Research whose appointment was made possible through a vote of the Council in accordance with Constitutional requirements, has not yet been appointed.

PAPERS AND DISCUSSIONS.

One hears among the sections an over insistent demand for papers of an elementary educational character. Sometimes arrangements for papers or lectures of this character are made. Generally the result is a recital of the fundamental physical relations of light such as may be found in any book on photometry. What is needed to meet this demand is a popular exposition of our technical papers. Much of our most abstruse material is capable of such treatment, and dissemination of knowledge can best be furthered by non-technical treatment of the latest information in the TRANSACTIONS rather than by repetitions of the fundamental laws of light.

Our papers often fail to receive the discussion which they merit. Only a small proportion—say 15 per cent.—of our members attend the technical meetings. The papers are discussed chiefly by those present at meetings. The TRANSACTIONS would be of greater value if papers were submitted to members qualified to discuss them by means of written communications.

GENERAL OFFICE.

The society now occupies one room, in the Engineering Societies Building, New York. This does service as an office for the assistant secretary and a meeting room for the council committees. Additional vault space in the same building is utilized for storage. The large growth of the Society during the past year has taxed this office space severely. Any further considerable growth may render larger quarters necessary.

The additional clerical work involved in the addition of 500 members to the roll makes the provision of a clerk to relieve the assistant secretary, an advisable procedure. During the coming year such an increase in office expenses will probably have to be made.

To date leadership in the society's affairs has devolved upon members interested in scientific and engineering work correlated

with illuminating engineering. Those whose efforts are directed along lines of an artistic character, as architects, fixture designers and decorators, have manifested considerable interest in the welfare of the society, but in general have not been active in promoting that welfare. Between those two classes there appears to be an improved mutual understanding. The engineers and scientists feel keenly the need of coöperation on the part of the other class, and it is probable that as the understanding of one another's needs becomes more thorough, architects, decorators and fixture designers may come to engage actively in the affairs of the society and assume that part of the direction of its affairs which rightfully is theirs. With such a consummation, the society will have taken its next great step in advance.

(Signed) Preston S. Millar,
General Secretary.

ANNUAL REPORT OF THE FINANCE COMMITTEE FOR THE FISCAL YEAR 1910.

To the Council of the Illuminating Engineering Society:

In accordance with the provisions of the Constitution of the Society, the finance committee has, during the past year, exercised direct supervision over the financial affairs of the society.

The committee held monthly meetings except during the summer, made recommendations to the council on all matters submitted for examination and report, and examined and approved all bills paid by the society.

In the early part of the year Mr. W. S. Pangborn, a certified public accountant was commissioned to render the following services:

First, to oversee the society's books of account for the year 1910; second, to present monthly, through the Secretary of the society, a proved trial balance; third, to complete the audit of the books and accounts of the society for the year, and to furnish a statement of assets and liabilities and earnings and expenses.

The subjoined statement of the society's finances as given

in Exhibits "A," "B" and "C" is taken from the report of the auditor for the fiscal year 1910.

Deficit for year 1910:—It will be noted from the statement, Exhibit "B," that the expenses of the society for the past year were $485.88 in excess of the earnings. In analyzing the expenditures, the committee finds that some of the items included in the expense account for the year 1910 are in part properly chargeable to preceding years. For example, the cost of indexing the TRANSACTIONS for the past five years is charged against the year 1910 as this work was done and paid for during the past year. Again, some of the items of expense are in part properly chargeable to succeeding years. For example, the cost of an extra edition of back numbers of the TRANSACTIONS for members elected in 1910, 1911, etc., is charged against the year 1910.

Allowing for various items of the nature of those above cited, the committee feels that the excess of expenses over earnings for the past year may be looked upon as a *book* deficit rather that a *real* deficit. However, the fact remains that in the matter of its finances the Society has been traveling on an extremely small margin.

Dependence on income from advertisements in the TRANSACTIONS:—As shown in the auditor's report, the expenses for the past year were $2,421.19 in excess of the membership dues, including unpaid dues. The Society was therefore again dependent to a large extent for its financial support, upon the income derived from advertisements in the TRANSACTIONS. The Committee reiterates the view expressed in a former report "that the Society will not be on an entirely sound financial basis until the income derived from membership dues exclusively, is considerably in excess of the expenses."

Membership committee expense:—The cost of the campaign that was undertaken last fall to increase the membership of the society was $1,254.68. The dues from new members whose accession was directly traceable to the campaign, exceeded the above cost.

Convention expense:—With the exception of entertainment expenses, for which a special fund was collected, all expenses of the annual convention held in Baltimore were paid from the

treasury of the society. This procedure marks a precedent in that for the annual conventions held heretofore, a considerable proportion of the general expense was defrayed from a special fund collected for the purpose.

Lecture course expense:—In accordance with the financial arrangement with Johns Hopkins University, the society was reimbursed by the university for all expenses chargeable to the recent lecture course on illuminating engineering.

CONCLUSION.

The Committee concludes that if the activities of the Society are continued along present lines, the most rigid economy will be required to avoid a deficit the coming year.

Respectfully submitted,
A. A. Pope,
W. H. Gartley,
L. B. Marks, *Chairman.*

EXHIBIT A.—BALANCE SHEET—DECEMBER 31, 1910.

ASSETS

Cash:		
In bank	$604.80	
On hand	100.00	
Total		$ 704.80
Accounts Receivable:		
Members' dues—1910	$247.50	
Members' dues—1909	7.00	
Due for badges	9.00	
Due for advertising	647.00	
Bond interest, due Jan. 1, 1911	40.00	
Sundry charges to members in 1909 on account of "Transactions"	186.19	
Total		1,136.69
Property Accounts:		
Furniture and fixtures	$668.21	
Less depreciation (25 per cent.)	167.05	
Net	$501.16	
Badges on hand (22)	54.00	
Total		555.16
Investments:		
Northern Pacific Railway and Great Northern Railway bonds, $2,000.00		1,920.00

LIABILITIES.

Accounts Payable:		
Sundry creditors—schedule No. 1		1,343.19
Dues paid in advance		100.00
Total		$1,443.19

SURPLUS.

Undivided profits		2,873.46
	$4,316.65	$4,316.65

EXHIBIT B.—STATEMENT OF EARNINGS AND EXPENSES AND OF CHANGES IN SURPLUS FOR THE YEAR ENDED DECEMBER 31, 1910.

EARNINGS.

Members' dues, including unpaid		$7,084.00
Advertising, including unpaid		1,740.98
Miscellaneous sales of TRANSACTIONS		58.75
Badges sold—net profit		41.00
Members' certificates—net		14.58
Interest on bonds		80.00
Total		$9,019.31

EXPENSES.

"TRANSACTIONS"	$3,649.59	
Membership committee	1,254.68	
Convention committee	152.72	
1910 election	330.71	
General office	2,859.81	
Exchange on checks	8.78	
Depreciation of furniture and fixtures	52.79	
New York Section	579.54	
Chicago Section	267.81	
Boston Section	185.01	
Philadelphia Section	163.75	
Total		9,505.19
Deficit for year		$ 485.88

SURPLUS ACCOUNT.

Surplus, January 1, 1910, per report		$2,831.60
From "convention committee," account		599.50
From "special suspense" account—1909		5.00
Bond interest not taken 1909 statement		40.00
1909 dues collected but not charged		15.00
		$3,491.10
Depreciation of furniture and fixtures—'07-8-9	$ 114.26	
Dues charged off	17.50	
Deficit for year 1910	485.88	
Total		617.64
Surplus, December 31, 1910		$2,873.46

EXHIBIT C.—ANALYSIS OF GENERAL OFFICE ACCOUNT.

Rent of office	$ 396.00
Rent of storeroom	64.00
Rent of typewriter (at Mr. Shea's home)	12.25
Repairs to typewriter	52.50
Telephone and telegrams	98.21
Postage and express	229.60
Incidentals	37.09
Salary of assistant secretary	1,308.33
Salary of clerk (stenographer)	73.50
Office supplies	263.04
Honorarium to Miss M. D. Young	50.00
Car fares	7.65
Meals (largely on Mr. Shea's account)	49.38
Constitution and by-laws	40.95
Finance committee's report	15.30
Bonding treasurer	15.00
Auditor (certified public accountant)	75.00
Annual dinner	59.00
Towel service	9.51
Fountain pen	3.50
Total	$2,850.81

THE PROFESSION OF ILLUMINATING ENGINEERING.[1]

BY A. E. KENNELLY.

The world of leading professions outside of the military, is divided into two great branches; namely the scientific professions and the artistic professions. The classical scientific professions, that have decended to us from antiquity, are those of theology, government, law, and medicine. The classical artistic professions are those of music, painting, sculpture, dramatic art, and oratory. The watchword of the scientific professions during the centuries has virtually been "Truth," and that of the artistic professions "Elegance."

The need for the various professions has arisen from the same cause as the need for every guild and craft, from the same cause as has made every human specialty an asset to its possessor, as well as to the community in which it is developed, a cause deep in the nature of living beings. Biologists tell us that the propensity of habit formation can be detected in the behavior of single-cell organisms, the simplest protoplasmic living structures, and that the more numerous and complex the aggregation of protoplasmic cells in an organism, the more marked, in general, is the tendency to, and definiteness of, habit formation. It is largely to the facility born of habit, in physical and mental processes, that society owes the advantages and economies of specialized vocations and professions. Even those inherited talents, instincts, and endowments, which so frequently lead to the choice of a business or profession, are, in a certain sense, congenital habits.

When a habit which is useful to society is relatively easily acquired, without a long preliminary and unremunerative period of learning and apprenticeship, the habit is commonly called a craft, trade, or occupation. When, on the other hand, the useful group of habits under consideration is relatively difficult to acquire; involves a long preliminary period of training, and especially a severe period of intellectual training; so that many

[1] Inaugural address of President Kennelly.

aspirants fall off and fail during the training process, the group of habits is commonly called a profession.

In modern times the increasing complexity of our community life, and especially the increasing accumulation of knowledge and information, have raised several occupations to the rank of professions, and, in particular, certain engineering occupations. Engineering, as an occupation, must be of prehistoric antiquity; but engineering, aside from the military art, has only in recent times risen to the rank of a profession. Engineering, as practised in the middle ages, was but little more difficult to learn than a trade. Now it demands at least as long and severe a training as either law or medicine. In fact, it is hopeless to seek a full acquaintance with the whole field of engineering, so numerous and varied are its branches.

In return for the greater recognition on the part of the community for the engineer's group of habits and functions, there is an increased demand and responsibility exacted from him by the community. He is properly assumed to bring to his duties a larger knowledge and a wider experience. The difference between work done under the direction of his trained habits of thinking and acting, must be correspondingly greater than that which could be expected to follow untrained direction. From the standpoint of economics, the public demands that he shall justify its confidence in his greater knowledge and superior technical guidance.

In order, therefore, that an occupation shall rise to the rank of a profession, and maintain itself in that rank with stable equilibrium, it is necessary that there shall exist in the life of the community a steady and sufficient demand for the results of that occupation, that the habits of thought and action, as well as the fundamental knowledge and practical experience, in the occupation, shall be difficult and expensive, in time and effort, to secure, that the ultimate rewards may on the one hand repay the efforts of the successful aspirants, and be warranted, on the other hand, by the economics of the result, to the community.

Professions rise and fall in the course of time, according to the economic need for their existence, and to the effort that must be made in working for them. The greater the utility that can

be secured from them, and the greater the sacrifice demanded in securing the knowledge and experience necessary for practising them, the greater their security. Under reverse conditions, they lose ground, either from excess, or defect, of disciples. In the long run, and in stable communities, stable professions tend to increase the numbers of their practitioners sensibly in proportion to the growth of population.

One of the most recently risen professions is that in which this Society is immediately interested—Illuminating Engineering. The need for this profession does not arise from any newly awakened desire on the part of the community for lighting, except as a matter of degree; because mankind has depended upon artificial light for many centuries. Its need has arisen from recently increased facilities for producing artificial light, recently multiplied illuminants, increased knowledge concerning the nature, use, and maintenance of light sources, as well as of their relation to health, aesthetics, safety, and expenditure. Every new acquisition of wealth involves the expenditure of a certain proportion of that wealth in the administration of the remainder. If a community comes into the possession of a hospital, library, or city hall, a tax must be assessed for its maintenance. A wealth of new illuminants and methods of illuminating have come into the possession of the people, through progress in science, art, and civilization. A portion of this wealth must be expended in the proper disposition of these new possessions.

In the accompanying diagram, an attempt is made to represent the principal underlying arts and sciences upon which are based respectively the professions of Medicine, Law, Engineering, and Architecture. No such scheme can pretend to great precision, since the affairs of men are so complexly interwoven; yet it is believed that the general features of the scheme will commend themselves to analysis. The profession of medicine is seen to be intimately connected with the qualitative group of sciences (anatomy, biology, physiology, etc.) and, in lesser measure, with the group of exact sciences (chemistry and physics). Law is closely connected both with the qualitative and social groups of sciences (logic, ethics, philosophy, moral law;—

economics and business). Architecture is closely connected with the constructive, decorative, and aesthetic group of arts, and, in a lesser degree, with the economical and quantitative scientific groups. Civil, mechanical, electrical, and mining engineering are intimately connected with the quantitative and social scientific groups; but practically not at all with quali-

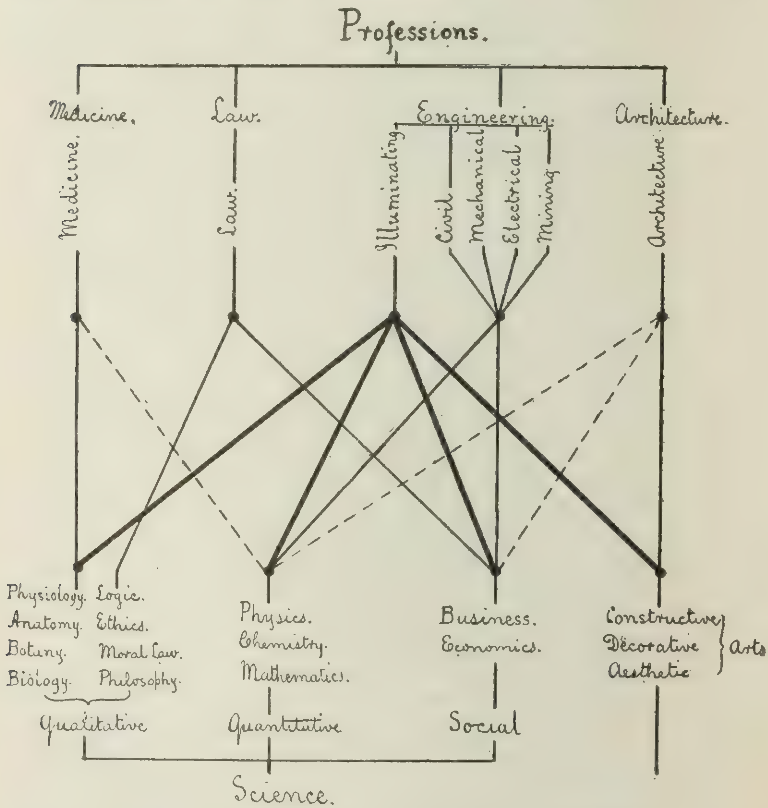


Diagram of arts and sciences underlying various professions.

tative science, or with art. It is to be observed, however, that illuminating engineering differs from the above mentioned branches of engineering, in being closely connected with all of the four groups, and it is the only profession which is in intimate relation with all of them (physiology, mathematics, physics, economics, business, and aesthetic arts).

In regard to the qualitative science group, the illuminating engineer is necessarily dependent on physiology, and is unable to fulfill his mission completely, unless he has studied the physiology of the human eye. Light which he controls and dispenses, is derived from radiant energy; but is actually a physiological stimulus. He not only has to learn much that the physiologist already knows concerning the function and hygiene of the eye under luminous stimulus; but has also need of learning and determining many facts, in these directions, that have not been considered of direct importance either to physiologists, oculists, or nerve specialists.

In regard to the quantitative group of sciences, the illuminating engineer is required to be familiar with the laws of optics, radiation, photometry, and illumination. He must be sufficiently familiar with arithmetical processes to be able, not only to understand the applications of these sciences, but also to compute the number, distribution, and strength, of the luminous sources he designs to install. In addition to the above, he should have such a knowledge of gas and electric distributing systems, as will enable him to make an installation with any system that may be available, and also such a knowledge of building construction, as will enable him to take advantage of structural features for his designs.

In regard to the economical group of sciences, the illuminating engineer must be trained to do all of his work with reference to its cost, and to the economy of cost. It must become instinctive habit with him to produce the best and most desirable results for a given expenditure, either as to first installation, or as to operation and maintenance. While constantly seeking improvements on the one hand, he must as constantly set prudent limits to hazardous experiments on the other. He must be essentially, to this extent, a business man.

In regard to the constructive and decorative arts, the illuminating engineer should possess, and be trained to develop, a keen sense of the artistic and aesthetic, as to form, color, luminosity, and architectural purpose. No great illuminating engineer can fail to be, to this extent, an artist and an exponent of art.

Finally, the successful illuminating engineer must possess, in common with most other engineers, a sympathetic understanding of other men's work, so as to be able to coöperate with all of the different men with whom he may be brought into contact in his designs, constructions, or examinations. Moreover, he will be more likely to need a sympathetic understanding of women's work than an engineer of any other class; because much illumination must please and minister to the needs of women, as well as those of men; while women will usually be the keener to appreciate the aesthetic quality of his work.

It does not, of course, follow that a successful illuminating engineer must possess all of the above-mentioned qualifications. We know that, in every profession, men succeed who are notably deficient in some of the qualities which they might be expected to possess. But we also know that they succeed not by, but in spite of, such deficiencies, and by reason of certain compensating advantages. It is a familiar example that we are all likely to trust to a less skilled individual, in whose honesty of purpose we feel certain, than to a more skilled individual, in whose honesty of purpose we feel doubt.

Nevertheless, particularly at the present time, when the profession of illuminating engineering is in its fresh youth, it is important that we should set a high standard for its intellectual habits and qualifications. Not only is it necessary for the illuminating engineer to do fine work, as judged by his peers, who understand it, but it is also necessary for him to do fine work, as judged by the public, who are not in a position to understand it, but are able to appreciate it. In the maintenance of every profession, the public delivers the final judgment as to utility and performance. The public will not accept illuminating engineering as a profession, unless there be a consensus of acknowledgment that the illuminating engineer repays his cost abundantly. Each and every individual is prone to believe that he or she can light a street, or a building as well as needs be, without aid or suggestion, and nothing short of absolute demonstration that a trained illuminating engineer will do it not only much better than an untrained haphazard man, but also manifestly better, will satisfy the incredulous.

I take it that this Society stands for the proposition that a competent, trained illuminating engineer can light a street, dock, office, factory, art gallery, theater, or home, very much better than the untrained, haphazard man. Not only this, but he will also demonstrate arithmetically wherein it is better, that there is by design ample light where it is wanted, and little or none wasted where it is not wanted, that there is no needless glare, that the cost of the lighting is moderate, and in harmony with the cost of the structures in other respects. Above all, he will be able, for this expenditure, to produce a much more graceful and pleasing illumination, in tones, intensities, colors, shadows, and harmonies, than the hapazard man.

The mistake is but too often made, that if the illuminating engineer provides the requisite distribution of light at a low cost, his duties are sufficiently discharged, without any reference to the aesthetic quality of his work. This performance would, however, be as defective as installing a graceful and pleasing set of light-sources, but without any regard to whether the illumination was adequate or excessive. It is in the absolute necessity of observing the rules of aesthetic taste, that the work of the illuminating engineer differs most markedly from the work of other classes of engineers.

The conscientious illuminating engineer is ordinarily called upon to be self-effacing and undemonstrative in the results of his work. It may be asserted, as a general rule, that any artificial lighting is aesthetically bad, which forces itself upon the undirected attention of the observer. Good lighting is harmonious and satisfying, but unobtrusive. If an observer enters a building, with its lighting in his mind, as the thing to be examined, then the criterion cannot be set up; but if, with his mind open, the first thing that forces itself upon his notice is the illumination, then that illumination cannot be aesthetic. A good illuminating disposition will so blend with an aesthetic environment as to enhance the sum total of pleasing effect; so that the visitor is incited to admiration; but it usually takes some little examination to perceive the share of merit due to the lighting. On the other hand, no amount of care given to the lighting may be able to retrieve the shame of an unaesthetic interior;

so that where the architect and decorator conspire to expel grace and elegance, the illuminating engineer, alone, may not be able to tempt them to return. Consequently, the work of the illuminating engineer may be marred by the work of his co-workers. Nevertheless, there is no situation so aesthetically desperate, but that care on the part of the illuminating engineer may somewhat improve appearances; or that carelessness on his part, may not make appearances still worse. If, then, an interior is pleasing to the eye, and brings pleasure to the visitor, by night, as well as by day, we may feel sure that all in its appearance is in harmony; so that all who have contributed to that appearance deserve praise, and the illuminating engineer among them. But if the interior is forbidding, and brings unrest to the gazer, it needs a special examination to determine where the guilt may lie.

An artist is likely to perceive quickly any defects in the aesthetics of lighting, either as to intensities of tone, shadows, contrasts, or colors, and an artist may, guided by his trained instincts, learn without much labor, how to arrange lighting sources aesthetically; but such a trained artist would probably fall short of the illuminating engineer, both in regard to providing satisfactory quantitative illuminations, and in providing the required lighting with least unnecessary expense. A high type of illuminating engineer should blend himself the artist, the engineer, and the business man.

If, however, the illuminating engineer is bound to maintain an unassertively co-operative attitude in the aesthetic side of his work, he is also bound to maintain a vigorously assertive attitude in regard to its hygienic or physiological side. It is a deplorable misfortune that an innocent and ignorant layman should hang powerful lights, with a brilliancy of perhaps several hundred candles per bright square centimeter, in the main line of sight, where an audience may gaze steadily, for an hour or more, at the orchestra-leader in a concert-hall, so that these sharp, bright points tend to fall constantly on the same spots of the weary retina. It is, however, unpardonable neglect, if the same fault be committed by the illuminating engineer. In every disposition of light sources that the engineer makes or examines, it is his duty to point out and remove excessive luminous inten-

sities from the lines of ordinary vision. The dangers attending the use of powerful lights are much exaggerated when considering healthy eyes, in ordinary healthy use; but weak eyes, staring foolishly for long periods at bright lights, may be much wearied, if not injured.

During daylight hours, when solar illumination is widespread, all objects within reach of the eye have a fairly equal claim upon our attention, save such as by their color contrasts, or large subtended solid angle, may happen to be salient in the momentary field of view. But within doors, at night, only artificially illuminated objects are able to reach our consciousness, through the avenues of the optic nerves. No object can find admission to our consciousness, save either by stimulating a sensation; or, by association of ideas, and memory. In a dark room, unless we grope, and use the tactile sense, immediate objects cannot ordinarily come to our consciousness, apart from the aid of memory. In the same room, lighted, the objects which are most likely to incite and hold attention, are those which can produce the strongest visual stimulus, *i.e.*, the most brilliantly illuminated objects. The illuminating engineer can accentuate the good appearance of a room, by bringing into stronger illumination the more beautiful or more interesting portions of it. Prominent among the brightly illuminated and clamorous objects are apt to be the lamps themselves. Hence it follows that the observer is constantly apt to be reminded of the existence of a bright lamp in the room, if it lies near the level of his eyes. If the lamp, as a whole, has pleasing form and color, and these suit the environment, the perpetual stimulus to reconsider the lamp, as a bright point on the retina, may not be unpleasant. Unless the lamp is too bright, and its visible surface has too high an intrinsic brilliancy, there may be either a conscious or subconscious pleasure in returning to its gaze. If, on the contrary, the lamp is unaesthetic, either in itself, or in relation to its environment, the frequent stimulus to review it, as a bright object, may be a source of either conscious or subconscious distress.

Apart from the question of whether pleasure or pain may be experienced by an aesthetically sensitive person, gazing and regazing at a bright lamp or fixture, we must admit that a grace-

ful object, is an object that mentally and morally stimulates; while an ungraceful object, mentally and morally depresses. The responsibility devolves then on selectors, and on designers, of lamps and fixtures, that their light may so shine before men, that these may add positive and not negative quantities to the sum of human happiness. The mistake is frequently made, in this connection, that a lamp, to be beautiful, must be ornate. As a rule, a lamp that is highly ornate is hard to make beautiful, except in harmony with specially ornate surroundings. Simple forms are more easily brought into beauty than complex forms, as the rococo, in art, attests. In the daytime, an ungraceful lamp, being unlit, may escape notice, but at night, when bright, its harshness may mar every retinal image. Every designer of fixtures is thus endowed, by the nature of his work, with a special influence for good or ill upon the community, and every illuminating engineer, who selects fixtures, shares this responsibility.

Some persons believe that illuminating engineering has already attained its full powers and only awaits a greater public recognition. Illuminating engineering already possesses, indeed, great powers; but these powers are rapidly increasing, and will probably increase very greatly. There is so much yet to be learned and accomplished. Thus, in dynamo-machinery, engineers have developed large generators and motors of over 95 per cent. efficiency; so that an ideally perfect machine could exceed the existing machines, in point of efficiency, by only about 5 per cent. But illuminating engineers have, as yet, developed, in light-sources, efficiencies of only a few per cent.; so that the ideally perfect lamp could give many times more light for the same power consumed. Much also remains to be investigated and ascertained in installing, applying, maintaining and measuring light-sources. An enormous field lies open to the members of this Society, a field approachable alike from the aesthetic, the physiological, the economical, the physical, or the manufacturing sides.

Another large and promising field open to illuminating engineering is the production of luminous colored decorative effects, both out of doors and within. Recent international and national exhibitions, such as those at Chicago, Paris, Buffalo,

and St. Louis, have demonstrated what beautiful decorative building effects can be made, at night, with ample and artistically arranged lighting. The tendencies of recent times in large cities have been towards greater display in illumination at night. This has perhaps been not so much owing to improved facilities for lighting, as to an increased demand and appreciation, on the part of the public, for luminous decoration. The training of the public eye towards the appreciation of the beautiful in luminous display is probably slow, just as in the training of the public ear to the beautiful in sound is, and has been, slow, as the history of music demonstrates. In the interior decoration of large public buildings, relatively large expense in sources and patterns of colored light may be more than repaid to the community, if aesthetic pleasure is produced, just as a fine symphony orchestra is an intellectual and emotional asset to a large city far beyond its cost. As time goes on, we may look for closer coöperation between the architect and illuminating engineer in producing color poems, during times when the landscape has been forbidden by the setting sun to steal away the gaze of admiration.

Finally, it is incumbent upon us all, as members of this Society, to advocate in our daily lives the purposes it fosters. We do not all have to wait for large occasions on which to display our purposes. Whether we attend to the lighting of a large hall, or a little one, a great theater or a small study, we should seek either to form, or to intensify, the habits of illuminating engineering, which are always to bring grace as well as cheer, beauty as well as brightness, ample illumination where scrutiny is needed, sparing illumination where only a clear passageway is sought, avoiding unnecessary glare and excessive brilliance, all with the maximum harmony, reliability, convenience and economy. It is our duty to aid the oculist, and medical man, in preserving at all times the hygiene of the eye, to see that the eyes of the student receive adequate light, with no unnecessary glare, or specular reflection, from the studied page, and to check all unnecessary waste of energy in uselessly burning lights. All artificial light beams are so precious to mankind in their history, traditions, and applications, that none should be allowed to go to waste where men cannot perceive them. Fire and firelight probably

marked the transition of the anthropoid ape to the simian man, a tremendous psychological distinction. It is only proper that we, who owe so much to artificial light, through its cumulating beneficent influence on many generations of our ancestors, should return reverence for its radiance, and enhancement for its luster.

REFLECTION CO-EFFICIENTS.[1]

BY PAUL F. BAUDER.

In presenting this paper before the Illuminating Engineering Society the author wishes, primarily, to bring out the necessity for obtaining more definite data upon the absorbing and reflecting values of various surface media when used in conjunction with the many commercial, artificial and natural systems of illumination.

At present an illumination plan for any given interior does not lay sufficient stress upon the color requirements of the lighting source, whether natural or artificial, combined with the walls, ceiling, floor and contents of the given interior. In order to present more fully the importance of the above details in the illumination specifications for given interiors one must consider not only the efficiency of the lighting sources with which the illuminating engineer must work, but likewise the combined artistic and architectural effect produced by the given installation.

An immense amount of work has been done to impress upon the mind of the engineer, as well as the general public, the fact that certain sources of light compare closely to what has been termed daylight. Investigations have been carried out to disprove such statements, and there is no tendency, at the present time, to describe an artificial illuminant as one which will produce daylight. No artificial illuminant as at present manufactured and installed, can combine intensity, color value, direction, brilliancy, volume and diffusion of light, in the same manner as they occur in natural light installations.

When the artificial light sources given in Table I are compared, upon the afore-mentioned basis, with daylight as a source, one is at once brought face to face with the fact that none is at present able to approach, except in a very small degree, the effect obtainable from daylight. The most important consideration is entirely missing, namely, the lack of adaptability of artificial sources to given interiors.

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, January 12, 1911.

TABLE I.—LIGHT-SOURCES.

ELECTRIC INCANDESCENT LAMPS.

Carbon
Graphitized carbon
Tantalum
Tungsten

VAPOR LAMPS.

Carbon dioxide
Nitrogen
Mercury-vapor (glass)
Mercury-vapor (quartz)

ARCS.

Open
Enclosed
Luminous
Flaming

INCANDESCENT FILAMENT.

Nernst

GAS.

Open flame
Incandescent mantle.
Acetylene

OIL.

Gasoline vapor used with incandescent mantle.

In making final decision as to what type of artificial illuminant should be used in lieu of daylight the illuminating engineer is initially impressed with the failure of the artificial source to give anything like satisfactory results, from the standpoint of color values obtained, as compared with the same results obtained from daylight.

The second item that is usually considered in connection with the commercial use of any given type of illuminant, such as shown in Table 1, is the efficiency of operation. Excluding this the engineer usually accepts any given type so as to meet his individual commercial inclinations.

The third detail, which is considered the most important, is to cover a given area with a proper intensity of light by the use of the selected sources. It is true that the location of the given light source is usually made to conform to the given architectural requirements. It has been contended, however, by several authorities that the selection of given illuminants should depend

primarily upon the color of light and reflector, color of interior surfaces, character of work to be done under the given light, etc., all of which items must be decided upon, primarily, from the consideration of what effect a given light has upon the average human eye.

With all of the developments which have been made in the manufacture of light sources, it has been a surprise to find that nothing radical has been done by paint, paper or tapestry manufacturers to make any given interior decorative materials harmonize with given light sources any better than they did when less efficient and thoroughly unsatisfactory methods of illumination were in general use.

The excellent paper presented before the New York Section of the Illuminating Engineering Society last March by Mr. C. R. Clifford indicates, in a general way, what should be considered from an aesthetic standpoint in the relationship of decoration to the illuminating engineer. In order to obtain the basis for a further estimate as to the importance of reflection and absorption in planning interior illumination, there are presented in Table II the results obtained by Dr. Herbert E. Ives for a 3.1-watt per candle carbon and a 1.25-watt per candle tungsten lamp, as to energy-flow and sensation values, and which are shown in a paper presented before the society on March 17, 1910.

TABLE II.—ENERGY-FLOW VALUE BY WAVE LENGTHS. SENSATION VALUES.

Source	0.43	0.47	0.51	0.55	0.59	0.63	0.67	Red	Green	Blue
Blue sky	185.0	180.0	146.0	120.0	100.0	87.0	77.0	26.8	27.2	46.0
								32.0	32.2	35.8
Carbon lamp	7.0	18.0	34.5	62.0	100.0	148.0	204.0	50.9	40.6	8.5
								51.3	40.4	8.3
Tungsten lamp	10.2	22.8	40.5	66.5	100.0	138.0	179.0	47.9	41.1	11.0
								48.7	40.5	10.9

As noted from the above table the energy-flow value by wave lengths for the carbon and the tungsten lamp varies considerably from the values for blue sky. The comparison for the wave lengths given between the carbon lamp and the tungsten lamp show considerable variation in the actual energy-flow values of these two incandescent lamp sources, and when considered in connection with the sensation values of red, green and blue, it is immediately noted that the various colors composing the

spectra of these two sources can be turned to more efficient value by not only using the proper reflector but likewise the proper interior surface coverings, in such locations as either of these two sources may be used. So great is the variation of these light sources from the color of daylight that interior decorations, from an artistic and chromatic standpoint, cannot be satisfactorily selected for only daylight effect, but should be selected with considerable attention to the effect which is produced in the interior when artificial illumination is used.

Present conditions of living require the use of such a great number of hours of artificial light that particular attention should be paid to the use of given interiors when artificial light is used, in order to obtain not only maximum lighting efficiency but likewise maximum artistic effect from the complete installation of light source and surroundings.

In order to appreciate more fully what effects are produced by the various colors of light forming the spectrum of any given source, attention may be called to Table III, showing the various effects accentuated with red, green and blue light falling on various fabrics of red, green, blue and white, as obtained by Mr. Chevreul, at the Goblin Tapestry Works, with additions by Mr. W. D'A Ryan.

TABLE III.—EFFECT OF COLORED LIGHTS ON ANILINE DYED MATERIALS.

Red	rays	falling	on	white	make	it	appear	red.
"	"	"	"	red	"	"	"	deeper red.
"	"	"	"	green	"	"	"	yellowish gray.
"	"	"	"	blue	"	"	"	violet.
"	"	"	"	black	"	"	"	rusty-black.
Green	"	"	"	white	"	"	"	green.
"	"	"	"	red	"	"	"	yellowish brown.
"	"	"	"	green	"	"	"	deeper-green.
"	"	"	"	blue	"	"	"	bluish green.
"	"	"	"	black	"	"	"	dark greenish gray.
Blue	"	"	"	white	"	"	"	blue.
"	"	"	"	red	"	"	"	purple.
"	"	"	"	green	"	"	"	bluish green.
"	"	"	"	blue	"	"	"	deeper-blue.
"	"	"	"	black	"	"	"	bluish black.

It is not possible to consider an installation of given sources of light solely from the standpoint of color values which are

retained, or slightly changed, but the incorrect use of the lighting source for given interior decorations, is liable to fail completely in producing a pleasing or satisfactory effect. Other considerations must be met by such installations of lighting sources, some of which have been previously noted.

The application of many of the characteristics of daylight,—chief among which is diffusion of light,—cannot be obtained by the use of artificial illuminants,—no matter in what way they may be used. If it were possible to diffuse the light from a given artificial source, and if this diffusion could be obtained in a fashion similar to that in daylight, many of the difficulties of interior illumination would be eliminated. The importance of properly diffusing the light has been given no serious consideration by the manufacturers of interior finishings, such as paint, wallpaper, tapestry, etc., applied to walls, ceilings, floors, furniture, etc.

It is impossible to obtain the diffusion of light which occurs in nature by suspended particles of foreign substances in the air, but it is possible to obtain diffusion of light as satisfactorily as it is obtained in nature by diffused reflection from various surrounding objects, such as ground and building surfaces. The proper application of artificial lighting units to interiors should allow for the correct diffusion of the light by surface reflection.

Particular attention, it is true, is paid by the interior decorator to the artistic and aesthetic values of any interior furnishings, including, likewise, the lighting unit. Due to the fact that sufficient authentic data are not at hand, it is to be doubted if the proper amount of consideration has been given to the adaptation of proper interior surface coverings to be used to obtain maximum diffusion of light as well as the most artistic and efficient illumination.

A proper psychological effect with a given installation cannot be produced without the use of some type of wall, ceiling and floor covering, which is best adapted for use with a given type of light source, combined with a given type of reflector.

Many times the pleasing effect obtained from the use of given interior finish for walls, ceiling, floor and decorations, is not by any means the most efficient combination which can be obtained from a lighting standpoint. Many times the lighting source is

so hidden by the use of shades that the actual amount of light delivered to the room is only a few percent of the total amount of light generated by the source itself. This condition can easily be remedied if the proper attention is given to the selection of any one of several types of artificial lighting sources, combined with properly tinted reflectors.

The results which can be obtained by the use of different types of reflector with two differents types of interior decoration are shown in the accompanying illustrations. The experimental work in obtaining these results was recorded by Messrs. A. L. Parsons and H. W. Smith, in a report upon "The Illumination of

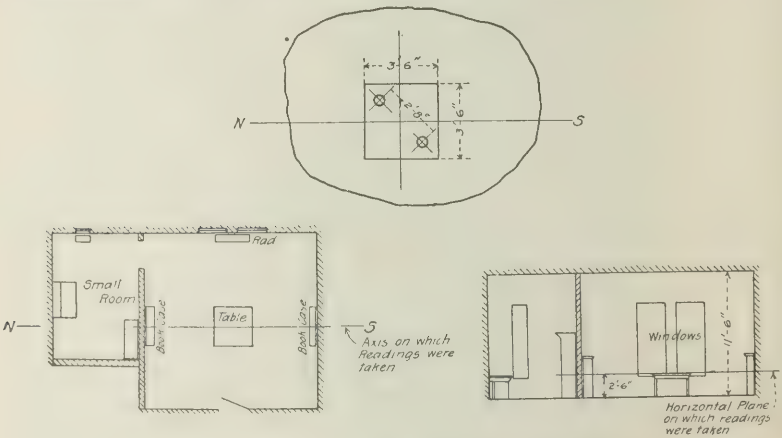


Fig. 1.—Plan and elevation of room, and center view showing position of lamps.

Study Rooms," submitted to the Superintendent of the Naval Academy, in Annapolis.

The rooms in which the experiments were made are illustrated in the accompanying elevations and floor plans of Fig. 1. The same furniture was used in room during all the tests, and the decoration of walls and ceiling indicated in Fig. 2 which is described in the following curves of illumination as "Original Decoration" is as follows:—Plastered walls and ceiling; former painted with light reddish brown, matt surface, oil color; latter are dead white, either painted or whitewashed.

"The Redecorated" rooms were the same as those indicated by "Original," with the following changes in coloring of walls

and ceilings:—The color selected for the walls was a light greenish-yellow, which, by the light of tungsten lamps becomes a pleasing yellowish green. "Other similar tints are suitable, but in general we prefer a tint tending to yellow for shady rooms, and one tending to green for sunny exposures." The walls were finished with a dado, extending to a height of four feet, and of a slightly darker tone than the main wall surface. The ceiling was painted a white slightly tinted with yellow. The ceiling color was extended downward about fifteen inches to a picture molding, in order to reduce the apparent height of the room.

The illustrations given by Figures 3, 4, 5 and 6 show the illumination results obtained with an illuminometer, and the units used were tungsten lamps equipped with various types of prismatic reflectors.

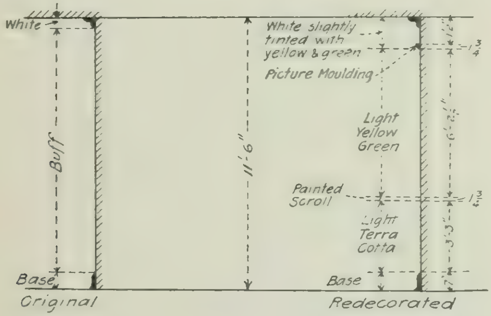


Fig. 2.—Arrangement of room, showing color scheme.

The data shown indicates that reflection from interior surfaces varies the resultant effective illumination to a considerable extent, according to the type of reflector used.

Some of the conclusions which were obtained from the large amount of data are as follows:

1. That re-decorating the rooms (in which the tests were carried on) decreased their apparent height, and rendered their general aspect more pleasing. The tint of the ceiling decreased somewhat the illumination over the working area, but this loss in efficiency was not sufficient to warrant the retention of the dead-white surface.

3. That a very substantial part of the effective illumination was due to light reflected from walls and ceiling.

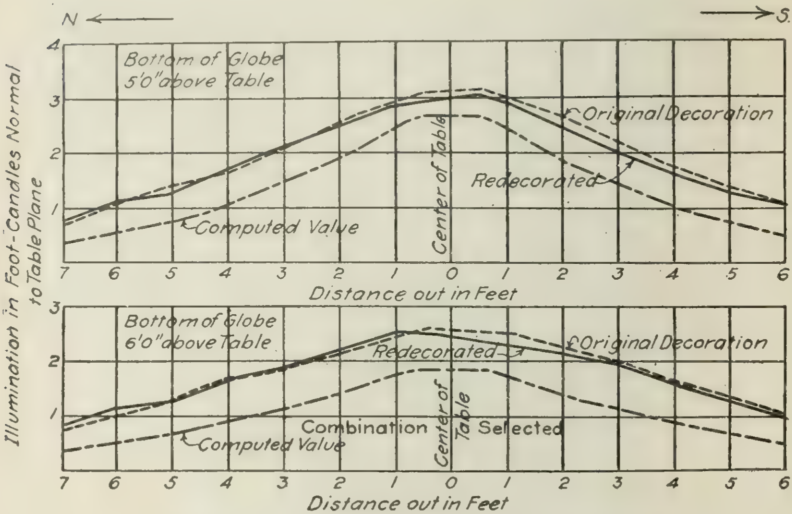


Fig. 3.—Illumination with two short-base clear 40-watt tungsten lamps in prismatic reflector.

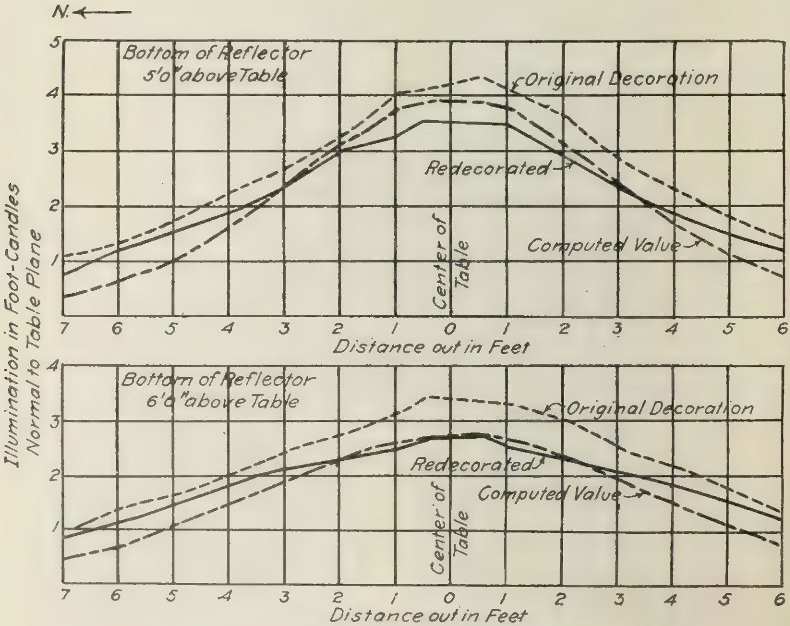


Fig. 4.—Illumination with two long-base frosted tungsten lamps in intensive prismatic reflectors.

The effect which might have been obtained from a proper combination of lighting source and reflector tinted to some shade matching the colors of the light source as well as those of the re-decorated room, would have materially increased the artistic if not the lighting efficiency.

So far as the author is aware, no results of a definite character have been submitted to the Illuminating Engineering Society as to the use of reflectors of different tints of glass with the different

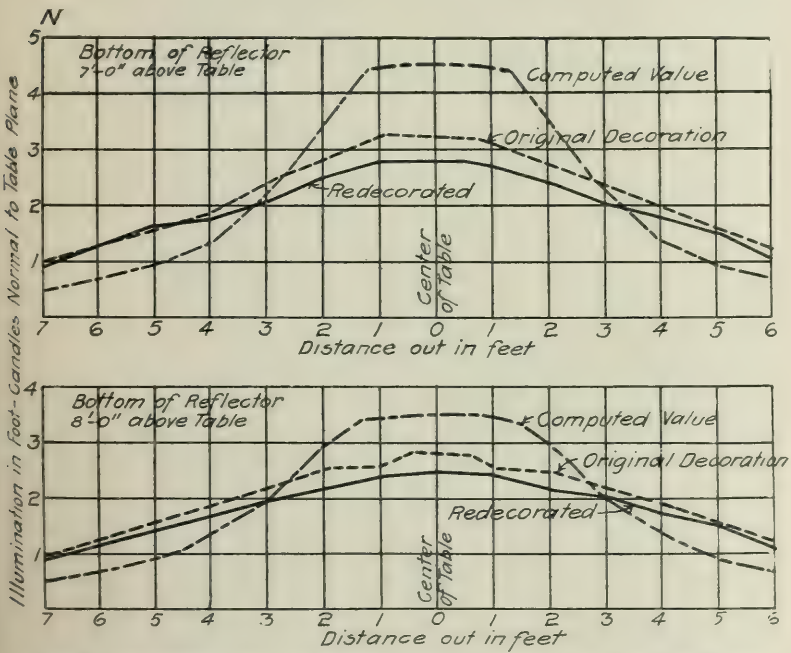


Fig. 5.—Illumination with two 40-watt long-base frosted tungsten lamps in focusing prismatic reflectors.

types of interior wall, ceiling and floor coverings. It is true that an interior of any one size could not be taken as a standard from which to work out the effects produced by the use of such types of reflector and lighting source as are commercially used at the present time.

The results obtained by Mr. F. H. Gilpin, as recorded in the paper presented before the Philadelphia Section of the Illuminating Engineering Society, on October 21, 1910, show the effect

of the variation of the incident angle on the co-efficients of diffused reflection. This paper contained a most interesting explanation of results carried on with the lighting source, an upright mantle gas burner, with a clear chimney. The results obtained clearly indicate that various kinds of paper, such as were used, vary greatly in their efficiency of diffused reflection. The table of data, if properly used, indicates the scope of work which can be done in continuing the results of these investiga-

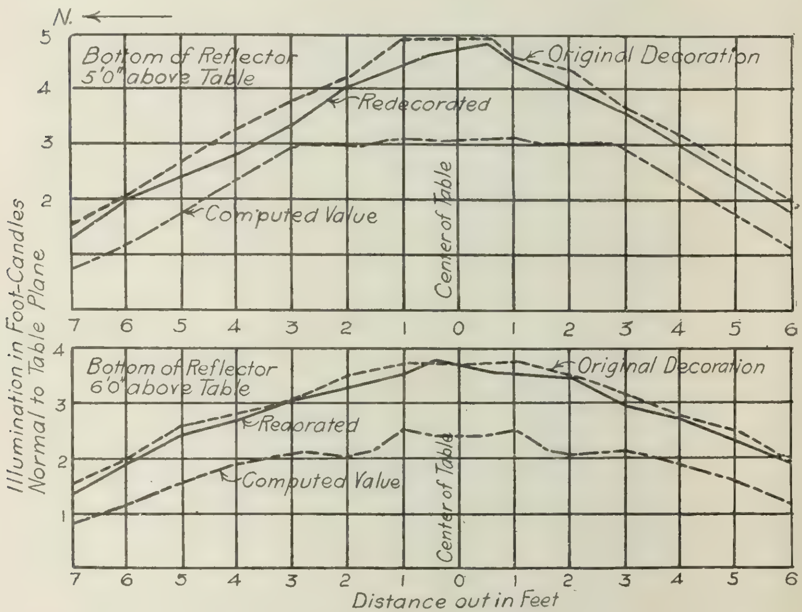


Fig. 6.—Illumination with three 40-watt long-base frosted tungsten lamps in extensive prismatic reflectors.

tions to many different types of wall, ceiling and floor covering, for the architect, interior decorator and finisher. The following conclusions by Mr. Gilpin are of interest in application to the present paper. "For high, narrow rooms, for indirect lighting or where the lamps are placed near the walls, a glossy paper will give the best results; while for wide flat rooms, or centrally located lamps, the difference between the rough and the smooth papers would be practically negligible."

Tests which were carried on by the author about two years ago

were made in conjunction with a study of the quality of light of various artificial lighting sources, as compared with daylight. The tests were carried on in a room shown in Fig. 7, ten feet square by ten feet high, and the wall coverings were varied from white to red, green and blue while the floor was white in the first instance after which the covering was removed leaving a dark wood floor. The illuminants used in this case were clear incandescent lamps in extensive type prismatic reflectors, and the results of the illumination in foot-candles were ascertained by the use of an illuminometer at different stations indicated in the accompanying drawing.

The object of obtaining these values was to determine the

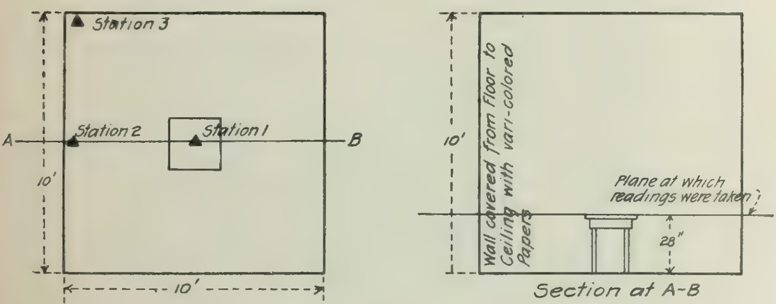


Fig. 7.—Plan and elevation of test room.

co-efficients of reflection for colored wall coverings as compared to a room having white floor, walls and ceiling.

Previous to carrying out the tests of illumination in the room above described, the color values of the fibrous red, green and blue paper wall coverings were taken with a colorimeter, and compared with daylight, as standardized by several lamps obtained from the Bureau of Standards at Washington. These lamps had in turn been compared with the then adopted average standard of daylight obtained by Dr. Herbert E. Ives.

The method by which these values were taken is indicated by the accompanying photograph Fig. 8, of the colorimeter, as arranged for test. The magnesium block shown was replaced by a strip of each of the wall coverings indicated, namely—red, green and blue.

These values are as shown in Table IV.

TABLE IV.—COLORIMETER READINGS OF VARIOUS TYPES OF WALL-PAPER IN TERMS OF STANDARD DAYLIGHT.

Type of illuminant	Color of surface on which light falls. White			Red			Green			Blue		
	R.	G.	B.	R.	G.	B.	R.	G.	B.	R.	G.	B.
Daylight	100	100	100	190	89	100	91	171	100	57	122	100

Blue is taken as 100 in each case.

Several types of artificial illuminant were likewise used, namely—treated carbon, graphitized carbon, tantalum and tungsten filament lamps, without reflectors, were used to obtain the colorimeter values of the various wall-papers which were hung in the

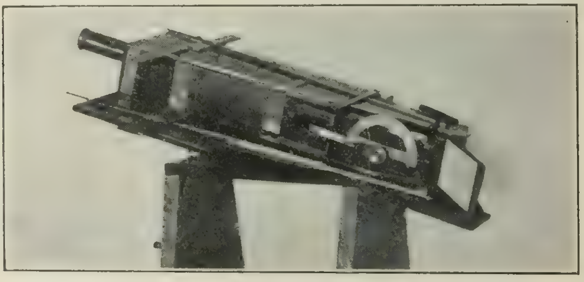


Fig. 8.—View of colorimeter, showing magnesium block.

test room. The incandescent lamps were so placed as to allow the maximum flux to fall normally upon the surface of the wall-paper.

These measurements of the sensation colors of the various surfaces upon which the light of each illuminant fell are indicated in Table V.

TABLE V.—COLORIMETER READINGS OF VARIOUS ILLUMINANTS.

In terms of standard daylight = Red 100, Green 100, Blue 100.

Type of illuminant	Color of surface on which light falls. White R. G. B.	Red R. G. B.	Green R. G. B.	Blue R. G. B.
Treated carbon	2575-1361-100	12080-1850-100	2170-1966-100	481-345-100
Graphitized carbon	1342- 788-100	8380-1525-100	1071- 812-100	421-324-100
Tantalum	1099- 592-100	3429- 640-100	1171- 877-100	242-204-100
Tungsten	780- 462-100	1850- 362-100	655- 670-100	209-178-100

A comparison of these results with those given in the previous table indicates the extent to which the artificial illuminants fail to approach the daylight values.

In making the illuminometer tests aforementioned, the incandescent lamp sources, in extensive type clear prismatic reflectors, were suspended about two feet below the center of the ceiling. The same reflector with different types of holder, corresponding to the lamp, was used for all of the tests. The incandescent lamps were photometered at rated specific consumption and the resultant constant voltage was maintained upon them during the test.

The sizes of the various lamps are as follows:

TABLE VI.—INCANDESCENT LAMPS USED IN TESTS.

Type	Specific consumption watts per candle	Total consumption watts	Approximate candle-power
Treated carbon	3.1	60	20
Graphitized carbon	2.5	50	20
Tantalum	2.0	40	20
Tungsten	1.25	25	20

The illuminometer measurements were taken at stations indicated in Fig. 7 as 1, 2 and 3, and the values for the several differing conditions of wall covering, viz.: white (white floor and ceiling), red, green and blue (the latter three with dark wood floor and white ceiling), are not given, as these values were reduced to percentages of absorption as follows:—

The white room (walls, floor and ceiling) values have been assumed to be maximum, and the illuminometer values for the rooms draped in red, green and blue have been expressed in percentages of reflection as indicated in Table VII for stations 1 and 2.

TABLE VII.—PER CENT. REFLECTION IN TEST ROOM.

	Station 1.			Station 2.		
Illuminant	Red Walls	Green Walls	Blue Walls	Red Walls	Green Walls	Blue Walls
Treated carbon	57.60	54.20	47.30	53.60	49.10	43.60
Graphitized carbon	56.95	51.85	46.90	48.40	47.80	44.65
Tantalum	50.60	49.00	45.75	49.35	50.10	47.90
Tungsten	49.15	51.60	50.90	47.45	51.70	49.97
	Station 3.			Average.		
Treated carbon	48.97	42.40	40.80	53.39	48.57	43.90
Graphitized carbon	47.25	48.40	42.00	50.85	49.35	44.55
Tantalum	47.86	49.70	44.68	49.27	49.60	46.11
Tungsten	45.0	49.95	50.26	47.20	51.08	50.38

NOTE:—All stations 28 inches above floor.

From the figures indicated in Table VII it is proven that, for the test room used, the absorption of light is a most important item. The variation occurring from the use of various colors of wall-paper in comparison to white wall and floor coverings is not as great as was expected before the tests were made. It is, nevertheless, evident that various results for higher efficiency of illumination could have been obtained if a different style of reflector had been used.

With decorative styles of shade, such as are given in Table VIII it is readily seen what an immense improvement has been made in obtaining higher lighting efficiency from reflectors over that obtained with the more or less strictly decorative styles of glassware.

TABLE VIII.—EFFICIENCY OF GLASS GLOBES.

Description	Absorption Per cent.	Efficiency Per cent.
Clear glass	5-12	88-95
Light sand blast	10-20	80-90
Alabaster	10-20	80-90
Canary colored	15-20	80-85
Light blue alabaster	15-25	75-85
Heavy blue alabaster	15-30	70-85
Ribbed glass	15-30	70-85
Opaling glass	15-40	60-85
Ground glass	20-30	70-80
Medium opalescent	25-40	60-75
Heavy opalescent	30-60	40-70
Flame glass	30-60	40-70
Signal green	80-90	10-20
Ruby glass	85-90	10-15
Cobalt blue	90-95	5-10

NOTE:—Light source not known.

From these results it is shown to what extent the use of inefficient globes decreases the efficiency of the source. Similar results should be obtained for interior decorations in order to combine the lighting source and interior as a complete illumination system rather than to consider each separately.

For certain locations there is more of a necessity to direct the light at once, without wall or ceiling reflection, upon the work at hand, and in order to accomplish this result steel reflectors of various surface finishes have been adopted. A considerable loss occurs, as the efficiency of reflection varies from 60 to 65 accord-

ing to the type of reflector, but the results from a correct illumination standpoint are apparently warranted.

A great deal has been and is being done by incandescent lamp and reflector manufacturers to increase the lighting efficiencies of the various styles of reflector, and the possibilities for manufacturers of interior decorations, such as art glass, wall hangings, etc., include a field of immense dimensions.

The illuminating engineer must, at the present time, determine for himself the many diverse details of not only the efficiency and adaptability of a given lighting installation, but likewise the utilitarian and artistic effect produced by it.

The intention of this paper is merely to indicate in a small measure what a necessity there is to consider the importance of reflection and absorption of light in obtaining the best from any installation of light sources.

DISCUSSION.

Mr. Norman Macbeth:—The studies of co-efficients of reflection are very valuable as tabulations, but it is very difficult to use them. However, there is one point worthy of commendation, namely, that the colors of papers used and also of the sources were measured with the colorimeter, working back from the daylight standard established by Dr. Ives.

In the matter of dyes, it is to be remembered that various colors have various selective absorption characteristics. A certain red may have a co-efficient of absorption different from that of another red where a different dye was used to produce the color. I recall an experience of an acquaintance who was a color expert in the carpet industry, which illustrates this very clearly. Each carpet expert keeps his formulas in a vest-pocket notebook, and when he leaves an establishment he takes his book with him; his successor must then take two pounds of No. 6 and a pound of number something else and attempt to secure the colors which the former man had used. The new man got along very well until he had to match colors for the staple lines of carpets used in residences. The factory had some sections of carpet returned to it where a strip of the new carpet was sewed to a strip of the older stock, which matched perfectly under daylight conditions, but not at all under different illuminants at night.

Whether the intensity of illumination should be higher on the ceilings and walls, or on a lower plane can be shown by taking brightness measurement. The measurements of apparent brightness can be taken in terms of the equivalent intensity on a white surface. I was interested in making some tests a month or so ago on indirect lighting because many photographs from the West, which is generally accepted as the home of indirect lighting, show the ceilings illuminated uniformly with a high intensity without dark spots or shadows. I found, however, that this was not the case.

Mr. Bassett Jones, Jr.:—That brightness measurements afford a good basis for comparison of installations is very true, but measurements of brightness, intrinsic brilliancy, watts per candle, etc., can not always be used to judge the merits of an installation. It must be remembered that the architect determines the conditions of the decoration, and it is not a question of adapting the decorations to the light sources, but the reverse. The lighting must be made an integral part of a room, so that the decoration can be seen well. One can go only just so far with his calculations; he must use his judgment, and stop where his judgment dictates. It is improper to assume that there are certain pre-determined ways of lighting a room. There are no such ways. Predetermination methods can be applied to many types of rooms, but in many other cases a sense of feeling of the effect which must be achieved in the rooms is the only correct guide to the solution of the illumination problem.

Mr. E. N. Hyde:—Referring to color and its special relation to decoration, mention should be made of the relation between brilliancy of color and quantity of light. It is quite noticeable that a piece of red cloth lighted at an intensity of two foot-candles increases in brilliancy when a reflector is placed over the light source thus increasing the intensity on the cloth to 6 or 8 foot-candles. If the architect or decorator has in mind a definite color scheme, he should take into consideration the number of lumens required to give the desired hues. With insufficient light the hues may not stand out in sufficient contrast, while with too much light, the hues may appear altogether too pronounced, and the contrast may be greater than is desired.

Mr. Bauder:—Illuminating engineering has been most successfully applied not only to the manufacture of incandescent gas and

electric light sources but also to reflectors; now the opportunities of applying it to the manufacture of interior finishings and decorations, so as to combine the whole into one complete unit, is apparent. The ordinary illuminating engineer, due to the fact that commercialism must decide for him what type of lighting unit must be installed, does not place due consideration upon the results which he expects to obtain by the use of one given style of illuminant. The combination of reflection from walls, floor and interior furnishings are such that if some accurate information were obtained as to surface reflection the engineer would be able to obtain much more efficient results than he is obtaining at the present time.

An example of the failure of an illumination plan to produce satisfactory results for the work at hand, was brought to my attention in one of the large Philadelphia department stores. This installation of tungsten-filament lamps, with prismatic reflectors, was intended for the silk thread and embroidery counter. At this location more attention was paid to slight variations in color than in almost any other location in the store. The opinion was received from one of the clerks that it was always necessary to take the sample to be matched to the window with several spools of silk, in order to obtain any degree of accuracy in matching colors. She picked out several samples of various shades of brown, in order to prove this statement, with the request that I select two which were alike. I did so easily when directly beneath one of the reflectors, but found it impossible to do so when holding the samples over the counter. The clerk was asked to do the same and proved to her satisfaction that similar colors could be matched, as I had done, without going to the window to do so. This fact merely indicates the failure of the engineer to consider the necessity, not of proper color of light, but of the proper quantity of light for this given set of conditions.

THE LIGHTING OF A STABLE.[1]

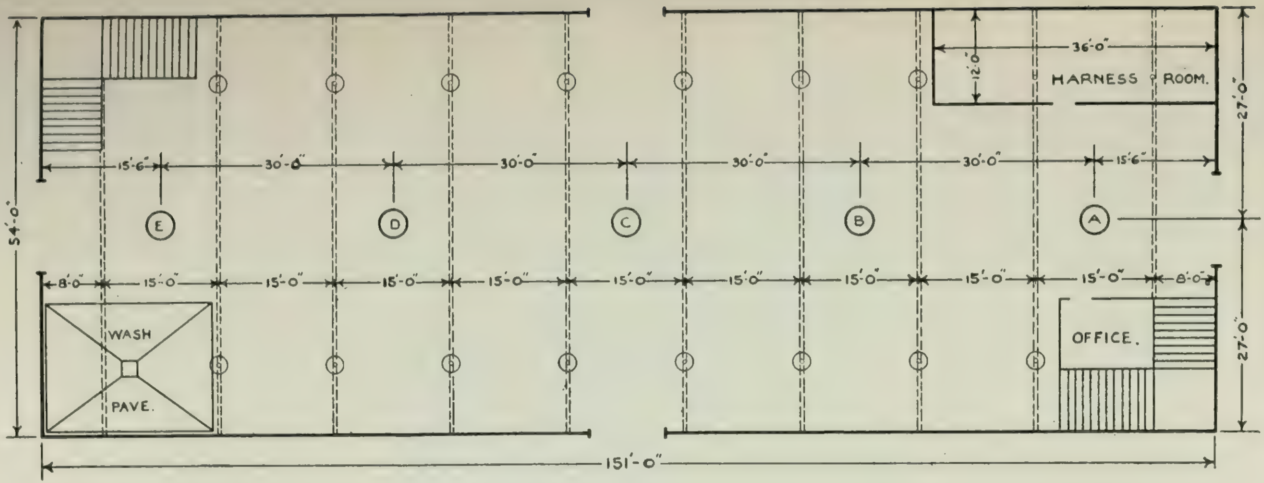
BY L. B. EICHENGREEN.

The problems confronting the illuminating engineer are becoming more varied each day. One problem which has thus far received scant attention, is that of stable lighting. Where gas is used in stable lighting, it is generally found that the lighting equipment consists of open flame burners or old style incandescent burners and cluster lamps. The problem which will be discussed in this paper is the relighting of the main stable building at Ninth and Diamond Streets, Philadelphia, and it is hoped that a description of this installation may prove interesting. In the first place it should be stated that the bulk of the work in the above stable must necessarily be done by artificial light, especially in the winter months, as the horses and wagons must be gotten out early in the morning, and do not return until evening. It is therefore of prime importance to have the most efficient lighting installation obtainable.

The stable will accomodate 75 horses and from 40 to 50 wagons, and, as shown in Fig. 1, which is a plan of the first floor, is 151 feet long and 54 feet wide. At the west end of the building is the wash-pave and auxiliary run-away to the second floor, and at the east end of the building are the offices and harness room.

The problem which had to be met in the general illumination of the first floor was made easy by reason of the location of the steel girders which are shown in Fig. 2. As the units which it was decided to install had to be placed as close to the ceiling as possible, it was found necessary to locate them midway between the girders, in order that the light might not be obstructed. At the outlets A, B, C, D and E, on which the old four-mantle upright arc lamps had been hung, it was decided to install the five-mantle inverted outdoor cluster lamp equipped with a clear globe. The photometric curve and gas consumption of this lamp were obtained at the laboratory, and it was found that while the quantity of gas used is practically the same as with the

[1] A paper presented at a meeting of the Philadephia Section of the Illuminating Engineering Society, December 16, 1910.



5 BURNER INVERTED LAMPS

HEIGHT OF LAMPS = 12'-6"

HORIZONTAL ILLUMINATION ON PLANE 49" ABOVE FLOOR.

STATION-	ACTUAL	CALCULATED
UNDER LAMP A.	5.55	8.32
MIDWAY BETWEEN LAMPS A & B	1.10	1.72
UNDER LAMP B.	7.22	8.34
MIDWAY BETWEEN LAMPS B & C	1.17	1.73
UNDER LAMP C.	7.22	8.34
MIDWAY BETWEEN LAMPS C & D	1.01	1.73
UNDER LAMP D	3.32 *	8.34
UNDER LAMP E.	6.60	8.32

* LAMP D OUT OF ADJUSTMENT.

Fig. 1.—First floor plan showing outlets.

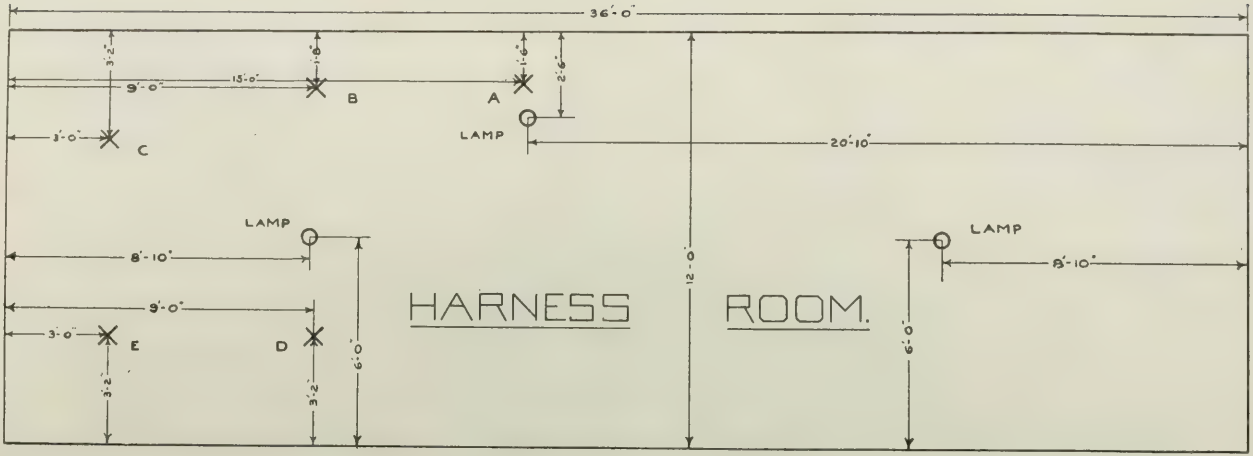
four-mantle upright cluster lamp, the mean lower hemispherical candle-power is much greater. Using the photometric curve as a basis for calculations, it was found that with the center of the mantles 12.5 ft. above the floor, the foot-candle illumination on a plane 49 in. above the floor, would be that shown in the table of Fig. 1. The lamps are located 15.5 ft. from each end of the building and 30 ft. apart. In making the calculations, the point-to-point method was used. After installation, the actual foot-candle illumination obtained on the horizontal plane was measured with an illuminometer. It was found that the actual

Fig. 2.—Interior view showing lighting equipment.

results, which are shown in the first column of the table of Fig. 1 approximated very closely the calculated results, the readings as seen being taken directly under each lamp and midway between the lamps. While the illumination directly under each lamp is considerably greater than that midway between the lamps, this did not become noticeable by the appearance of bright spots. Fig. 2, which was taken from the east end of the building, showing the harness-room on the right, is a daylight photograph. The location of girders and lamps is shown here quite plainly. The lamps are finished in white enamel, and each is

equipped with a magnetic cock installed directly above the ceiling shield. These cocks are not visible. Each cock is operated by means of a push button switch located on the office wall. Any lamp may be lighted or extinguished from this point. The wiring used in this work is the No. 18 B &. S. gauge office wire, the energy being obtained from dry cells which are found very effective.

The harness-room is 36 ft. long and 12 ft. wide. The harness is hung on the north and south walls and on racks extending down the center of the room. Lockers for the men are against the west wall. The sink, above which the harness is cleaned, is on the north wall. The harness cleaner works throughout the night. This room was formerly lighted with open flame burners, one being placed on a bracket just above the sink, and directly in front of the workman's eyes, and two each on two-arm pendants above the centers of the harness racks. Fig. 3 is a plan showing the location of the lamps. Illumination readings taken on a horizontal plane 49 in. above the floor at the stations A, B, C, D, E gave the results shown in the table of Fig. 3 marked "Old Installation." This illumination was found to be quite insufficient. The condition which influenced the selection of the new lighting unit was that practically all the light was required in the lower hemisphere. The unit selected was the single-mantle inverted outdoor gas lamp equipped with a reflector. The photometric curve of this lamp was obtained at the laboratory. It was found that by installing one lamp over the center of each harness rack and one over the sink, at a height of 9 ft. above the floor, the calculated foot-candle illumination, obtained on the horizontal plane 49 in. above the floor, would be fairly uniform and quite sufficient. The calculated and actual illuminations obtained with the new installation are shown in the table of Fig. 3 under "New Installation." By comparing the old and new installations, it will be found that the foot-candle illumination has been increased by about 30 per cent.; the amount of gas used with the new installation is about 12 cu. ft. per hour as against 35 cu. ft. per hour with the old installation. Fig. 4 is a daylight photograph of the new installation, showing the west and center lamps. These lamps are finished in white enamel and are controlled by by-pass cocks



OLD INSTALLATION.

Station.	Actual.	Plane.
A	2.75	All readings taken on a horizontal plane 49" above floor.
B	1.17	
C	.49	
D	1.15	
E	.46	

NEW INSTALLATION.

Station.	Actual.	Calculated.
A	3.61	5.53
B	1.70	3.25
C	.75	1.25
D	1.97	3.31
E	.64	.98

HEIGHT OF MANTLES 9 FT ABOVE FLOOR

Fig. 3—Plan of harness-room.

operated by individual chains. The lamps are so placed as to be out of line of vision and every detail of the harness can be clearly seen.

The wash-pave presented a more difficult problem, as it was necessary to locate the lamps at some distance from the wagon in order to place them out of the direct range of the splashing water; at the same time it was desired to obtain a uniform and good illumination all over the wagon. The wagon washer works throughout the night.

In the old installation seven open flame burners equipped with

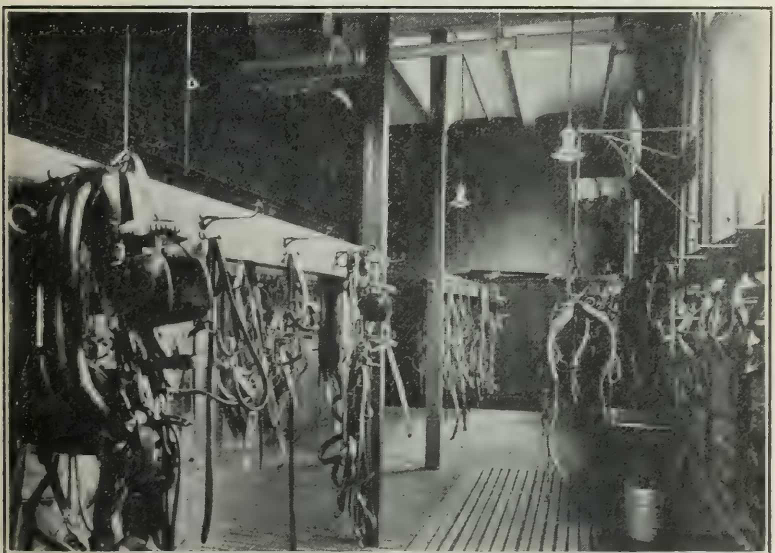


Fig. 4.—Interior of harness-room showing lighting equipment.

concave mirror reflectors were located rather indiscriminately around the wash-pave. It was found impossible to keep the reflectors whole for more than a few days because of the splashing water. The new unit which it was thought would be most suitable for this installation was the single mantle inverted gas lamp, equipped with an angle reflector. Upon testing this unit, the candle-power distribution curves shown in Fig. 5 were obtained, the readings being taken in vertical planes; the curve on the left is that obtained in a plane through the center of the

mantle and the centre of the opening in the reflector; the next curve to the right is a plane through the center of the mantle and half-way between the center of the opening and the side of the reflector; the third curve is in a plane through the center of the mantle, and the edge of the opening in the reflector. Using these curves as a basis, quite a number of calculations were made, changing the number, height and location of the units. The installation finally adopted is that shown in Fig. 6 which is a plan view of the wash-pave. Six lamps were installed 8 ft. above the floor, with the exception of the lamp K which is 10.5 ft. above the floor in order to clear the top of the wagons, which are pulled out beneath it. Three are against the west wall, the south lamp being 1.25 ft. from the wall, and the other two lamps being 6.5 ft. apart. Three lamps are 22.7 ft. from the west wall and

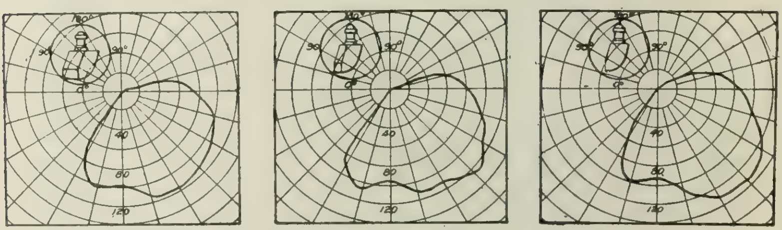
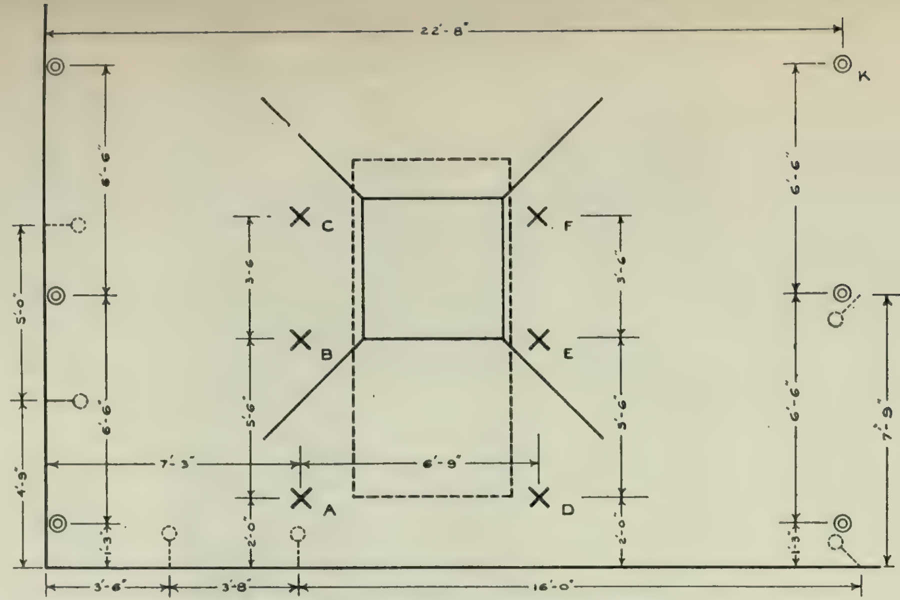


Fig. 5.—Candle-power distribution curves.

parallel with it, and are spaced similarly to the first three lamps. These lamps are shown by the solid concentric circles in Fig. 6. The location of the open flame burners is shown in this view by the dotted circles. Foot-candle illumination measurements were made with the old installation, readings being taken on both the horizontal and the vertical planes 2.75 ft. above the floor, at the stations A, B, C, D, E and F. These readings which are shown in the table of Fig. 6 are seen to be quite low. In the table are also shown the calculated and actual results obtained with the new installation, these readings being taken on the horizontal and vertical planes 2.75 ft. above the floor, with the stations as above. The actual measurements shown in the table of Fig. 6 were made with the wagon in position, ready to be washed. The results with the new installation, show a very uniform illumination on both the horizontal and vertical planes, the foot-candle



OLD INSTALLATION. — OPEN GAS FLAME.

NEW INSTALLATION. — PORTICO LAMPS WITH SPECIAL ANGLE SHADE.

STATION.	OLD INSTALLATION. ACTUAL HORIZONTAL	OLD INSTALLATION. ACTUAL VERTICAL	NEW INSTALLATION. ACTUAL HORIZONTAL	NEW INSTALLATION. CALCULATED HORIZONTAL	NEW INSTALLATION. ACTUAL VERTICAL	NEW INSTALLATION. CALCULATED VERTICAL
A	1.96	.74	1.70	1.51	1.84	2.21
B	.95	.53	1.39	1.86	1.86	2.95
C	.74	.50	1.64	1.69	1.71	2.75
D	.65	.52	1.60	1.16	1.59	2.23
E	.57	.47	1.80	1.35	1.74	2.43
F	.66	.46	1.86	1.40	1.48	2.07

HEIGHT OF ALL LAMPS EXCEPT LAMP K = 8 FT. ABOVE FLOOR.
HEIGHT OF LAMP K = 10'-6".

ALL READINGS WERE TAKEN IN A HORIZONTAL PLANE - 2'-9" ABOVE FLOOR.

Fig. 6.—Plan of wash-pave.

illumination being 100 per cent. greater with the new installation. The consumption with the new installation is 21 cu. ft. of gas per hour as against 42 cu. ft. with the old installation. Fig. 7 shows a daylight photograph of the wash-pave with the new installation. The lamps on each side of the wash-pave were not placed parallel with each other, but were turned so as to face towards the center of the wash-pave. One of the five-mantle inverted lamps which forms a part of the general illumination scheme and which also helps to illuminate the front of the wagon, is shown in the photograph.

The problem of protecting the globes from the splashing

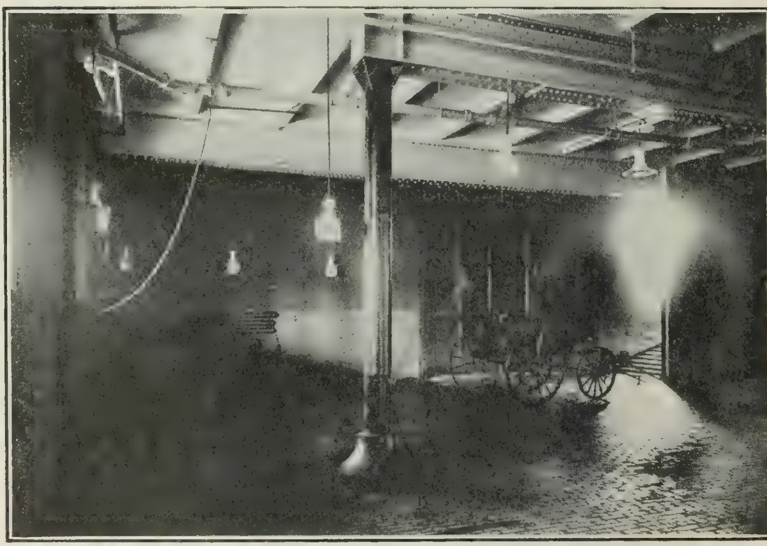


Fig. 7.—Lighting equipment of wash-pave.

water was a rather serious one. The angle reflector shielded the globe on the sides, but the front and bottom were left exposed. The scheme tried was that of closing the front and bottom of the reflector with removable glass plates, while the sides and top of the reflector were perforated for the circulation of air. It was found, however, that the heat caused the glass to expand and break. The plates were then split up into a number of sections or strips similar to the glass front in a "search-lamp."

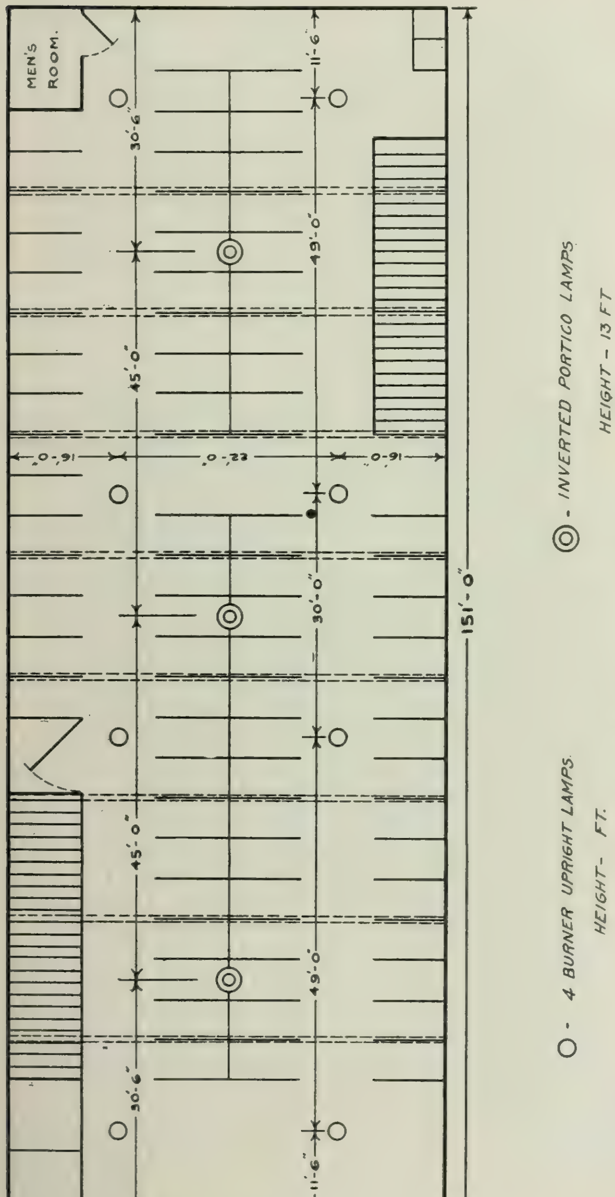


Fig. 8.—Second floor plan.

This scheme, while an improvement, was not entirely satisfactory, so that a combination which comprises the drilling of more holes, and the leaving of a narrow clearance space between the sections is now being tried; and so far has proved very satisfactory.

On the second floor are the stalls for the horses, there being a double row of stalls down the center of the room and a single row of stalls against each wall. In the single rows, the horses face away from the center of the room, while in the central rows, the horses face each other towards the center.

This room was found equipped with eight four-mantle upright cluster lamps; the location of these lamps, four down each aisle is shown in Fig. 8, which is a plan view of the room. The illumination from these lamps, which were provided with clear globes, was found to be all that was required to clean the horses and make up their beds. However, it was found that the lamps, when they were turned down for the night, caused a glare which disturbed the horses. It required several weeks for a new horse to become so accustomed to this condition that he could sleep comfortably. It was therefore decided to install three single-mantle inverted gas lamps, equipped with 7 in. alabaster ball globes, down the center of the room, over the heads of the central stalls, these lamps being 13 ft. above the floor, 30.5 ft. from each wall and 45 ft. apart. These lamps, which are used only after the other lamps are extinguished, give just enough illumination for the men to see to walk around, the regular lamps being turned on in case of emergency. It was found, however, that the single mantle inverted lamps gave more light than was wanted, and special hemispherical reflectors have been designed which hide the globe completely, and act as indirect reflectors, throwing all the light to the ceiling. This arrangement gives a soft pleasing illumination which is all that is necessary. Fig. 9 is a daylight photograph showing the new installation. This picture does not show the indirect reflectors. These lamps are controlled by magnetic cocks located just above the ceiling shield on the lamp. The cocks are controlled by push-buttons located in the mens room at the east end of the building.

On the Diamond Street side of the stable building are four lanterns, two on the gate-post at the west end of the building and two on brackets on either side of the main door. These

lanterns were equipped with open flame burners. The post lanterns which are 2 ft. high are hexagonal in section, the distance across flats being 10 in. The lantern door is 12 in. high and 4 in. wide. The construction of these lanterns was slightly modified so that in each lantern was installed a single-mantle inverted outdoor lamp equipped with a 7-in. clear ball globe, the center of the mantle being located opposite the center of lantern door, so that the stack of the lamp is hidden from view by the top of the lantern.

The lanterns on the brackets are 3 ft. high and hexagonal in

Fig. 9.—Lighting equipment of second floor.

section, the distance across flats at the top of the lantern being 15 in. and at the base of the lantern 13.75 in. The height of the door is 25 in. and the lantern is practically all glass. These lanterns have been equipped with special reflectors which fit into the top of the lantern, and throw the light from three upright mantle lamps up and down the street. The lamps are equipped with 9-in. chimneys which extend up through the reflector.

It will be noticed that outdoor lamps have been used throughout this installation, because in summer when doors and windows are open, the lamps are exposed to practically outdoor conditions

DISCUSSION.

Mr. W. R. Serrill:—In the harness room there was quite a discrepancy between the actual readings and the calculated readings, the calculated readings being almost double, in some cases, those of the actual. Is that result due to the fact that the harness was hung when the readings were made while no allowance was made for the harness absorption in the calculations?

Mr. R. B. Ely:—Is artificial light used in the loft? Why was a plane 49 in. high selected for the readings? From the readings taken it seems that the harness room is not as brightly lighted as the main stable. Was any allowance made for the reflection of light from the ceilings and the walls in the calculated readings?

Was the consumption of gas calculated on the rated consumption of the different lamps and the open burners, or was it a measured rating? Frequently in stables some protection is provided against falling glass. In electric lighting installations use is made of what is called "vapor-proof" globes. Has any protection been suggested or thought advisable in the case of gas lighting of that kind, especially in the straw room, where a piece of hot glass might cause fire?

Mr. C. O. Bond:—After the indirect illumination was put in place for the purpose of giving a low intensity when the horses were supposed to be sleeping, was it found that when new horses came in they would accustom themselves to the new condition more quickly than when there was a bright spot of light either above or in the vicinity?

It would be interesting to know whether any tests have been made to show what intensity of lighting horses like best. In the case of the harness room were any tests made while cleaning the harness by increasing the illumination until the workman was satisfied with it?

Mr. W. T. Dyre:—On the floor where the stalls are located, are the lamps controlled from the men's room by push-buttons, or automatically, or is a pilot flame used?

Mr. W. J. Serrill:—One of the most interesting phases of this question was the treatment of the lamps around the wash-pave. Before Mr. Eichengreen was consulted use was made of several more or less home-made ways of lighting the wash-pave,

and resort was always had to the open flame, with no reflector, because the splashing of the water would break any glassware used, Mr. Eichengreen seems to have solved this problem.

Mr. R. B. Ely:—Has a trial been made of mesh screening, or double screen interposed between the splashing of the water and the lamps?

Mr. J. D. Israel:—In the harness room there seems to have been a 50 per cent. saving in gas consumption due to the new installation. Did that ratio hold throughout the entire consumption in the building, and if not, what was the saving in consumption throughout the entire installation?

Mr. B. F. Deck:—On the second floor, where the stalls and horses are, use had formerly been made of four or six-mantle upright lamps. Can the author give any figures on the illumination from the new method? The three mantles now used must give considerably less illumination than was obtained previously.

Mr. Eichengreen:—In the harness room the calculated values were much higher than the actual values obtained. This was probably due to the harness obstructing as well as absorbing a great deal of light, as it is dead black, and was in place when the illumination measurements were made.

There is no lighting of any kind on the third floor which is the hay-loft. Wooden pitch forks are even used here to guard against fire being caused by sparks.

The reference plane in the harness room was taken 49 in. above the floor as this is the plane on which the maximum illumination is required by the workman in cleaning the harness.

The illumination in the harness room was probably somewhat lower than in the main building, and I think this should be so, as the man needs a high illumination only at the sink where the harness is washed; the harness hanging on the racks is illuminated just enough to render it visible for selection.

In making the calculations no allowance was made as to the amount of reflection received from ceilings or walls.

The amount of gas used was not determined by meter. The amount used in each separate room was estimated from the known consumption of lamps in practical service.

In protecting the globes use was made of wire netting which is fastened to the reflectors. The mesh is large so that the nets

are practically invisible. They will hold any broken globes in position until the cleaner can replace them.

On the second floor the globes on the lamps down the center of the room are protected very well by the indirect reflectors, which are entirely beneath them and will catch any falling glass.

As to whether a horse accustoms himself more easily to the new installation than he did to the old, I can only say that the man in charge of the stable stated that the new installation is much more satisfactory and the horses rest much better than they did before.

No tests have been made to ascertain the amount of illumination a horse likes best; it might be a difficult thing to determine.

In making the installation in the harness room the attendant was not consulted as to the intensity he would like best; after the equipment had been installed he found that he could do more work and do it better, and he liked the new installation much better than the old one.

The five-burner inverted lamps on the first floor and the single-burner lamps over the main stalls on the second floor practically have to be ignited by some other means than pulling a chain. To use a long stick or get up over the stalls would probably disturb the horses too much. In these cases use is made of a magnetic cock controlled by a push-button switch in certain parts of the building some of them at quite a distance from the lamps. These lamps can be ignited separately, so that there can be one lamp, or all the lamps in use. With these magnetic cocks use is made of pilot flames, the cock being opened and closed by means of an electric circuit. The current through one set of coils of the electro-magnet attracts an armature and pulls the lever on the cock in one position to open it, while the current through the other coil attracts the lever arm on the other side of the cock, thereby turning the plug to the closed position.

No attempt has been made to put a screen in front of the lamp in the wash-pave, as the screen would cut off the light from the wagon. We did, however, think of using a glass with wire screen embedded in it, but discarded this in favor of the glass cut in sections, with a small space between the sections, which arrangement prevents the water from splashing on the globes.

In the harness room the former five open gas burners consumed 35 cubic feet of gas per hour. The lamp which was installed burns 3.3 cu. ft. by laboratory test. The valve assumed was 4 cu. ft. per burner, which equals 12 cu. ft. per hour or about one-third of the gas used there before. In the wash-pave there were seven open-flame burners consuming 42 cu. ft. per hour while the new lamps burn about 24. On the second floor gas is probably saved by turning out the four-burner lamps which were formerly turned rather low in order to give just enough illumination for the men to see in walking around.

On the second floor it was found that the burner gave too much light and the horses were a long time getting used to it. Now the intensity is reduced and the light is much softer.

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MINUTES OF COUNCIL MEETING.

MARCH 10, 1911.

In the monthly report of the secretary at the meeting of the council held in the general office, March 10th, the total membership was given as 1,478 members. Counting the changes under consideration at that time this number would have been increased by three. The gross receipts from dues, advertising, etc., for the first two months of 1911 were said to have totaled $4,464.88, while the expenses for the same period had amounted to $1,671.87.

The executive committee reported that they had approved several committees which the president had appointed since the previous council meeting.

Mr. L. B. Marks, chairman of the finance committee, submitted a list of the February vouchers aggregating $419.33 which his committee had approved for payment, together with a report recommending certain economies which might be effected during the 1911 administration. The report was accepted and the payment of the vouchers was authorized.

Two amendments to the by-laws received a second reading and were adopted. Accordingly Articles IV, Section 1, now reads:

"The entrance fee shall be $2.50 payable on admission to the society."

The other change was made in the first sentence of Article VII, Section 2, so that it reads:

"Regular meetings of the council shall be held once each month, except during July, August and September."

Twelve applicants for membership were elected. One member was reinstated. The resignations of ten other members were accepted.

Those present at the meeting were President A. E. Kennelly,

L. B. Marks, chairman of the finance committee; James T. Maxwell, V. R. Lansingh, treasurer; A. S. McAllister and Preston S. Millar, general secretary.

SECTION MEETINGS.

CHICAGO SECTION.

The monthly meeting of the Chicago Section was held at noon, March 16th, directly following a luncheon at the Great Northern Hotel. A paper entitled, "Tests on Lighting of a Small Room," was presented by Mr. James R. Cravath. Participating in the discussion were Chairman F. J. Pearson, and Messrs. Albert Scheible, G. H. Stickney, T. H. Aldrich, L. G. Shepard, Arthur J. Sweet, M. G. Lloyd, G. C. Keech and Jas. R. Cravath.

At the meeting to be held April 20th, Mr. Chas. R. Gilman, electrical engineer of the Chicago, Milwaukee & St. Paul Railway, will present a paper on "Recent Developments in Train and Car Lighting."

NEW YORK SECTION.

The New York Section held its March meeting in the auditorium of Gimbel Brother's department store on Thursday, March 9th, a paper descriptive of the lighting installation of the store being presented at that time by Messrs Clarence L. Law and Albert Jackson Marshall. The paper was discussed by Messrs. V. R. Lansingh, P. S. Millar, J. S. Codman, S. W. Ashe, Norman Macbeth, H. T. Owens, G. H. Stickney, C. L. Law and A. J. Marshall. This paper appears in the present issue.

Papers dealing with photometric relations will be read by Messrs. Bassett Jones, Jr., and J. C. Pole at a meeting of the section to be held on April 13th. The paper by Mr. Jones will be entitled, "Polar Curves of Finite Surface Light Sources," and the one by Dr. Pole, "The Photometry of Mercury-Vapor Lamps." Copies of these papers have already been printed for distribution to members interested in the subject.

NEW ENGLAND SECTION.

The New England Section held a meeting on Feb. 13th, at which time a paper entitled, "Flicker on Fixed and Rotating

Targets," was presented by Messrs. A. E. Kennelly, G. R. Carter, S. C. Li and E. A. Healey. This paper appears in this number.

PHILADELPHIA SECTION.

A meeting of the Philadelphia Section was held on March 17th, when Dr. Herbert E. Ives presented a paper on "Standards of Luminous Intensity," illustrated with lantern slides and followed by a brief discussion. Those taking part in the discussion were: Messrs. L. B. Eichengreen, W. J. Serrill, W. H. Fulweiler, T. J. Litle, Jr., F. N. Morton, Geo. S. Barrows, and F. H. Gilpin.

FLICKER ON FIXED AND ROTATING TARGETS.[1]

BY A. E. KENNELLY, G. R. CARTER, S. C. LI AND E. A. HEALEY.

In a paper on "The Frequencies of Flicker at which Variations in Illumination Vanish" by A. E. Kennelly and S. E. Whiting, read before the National Electric Light Association, at its Washington Convention, in 1907,[2] the results of a research on flickering illuminations were reported. The present paper contains the results of an extension of the above mentioned research into the fields of different sizes of stationary targets, and also of rotating targets. In order, therefore, to present the new facts more clearly, the essential particulars of the earlier research may be briefly recapitulated.

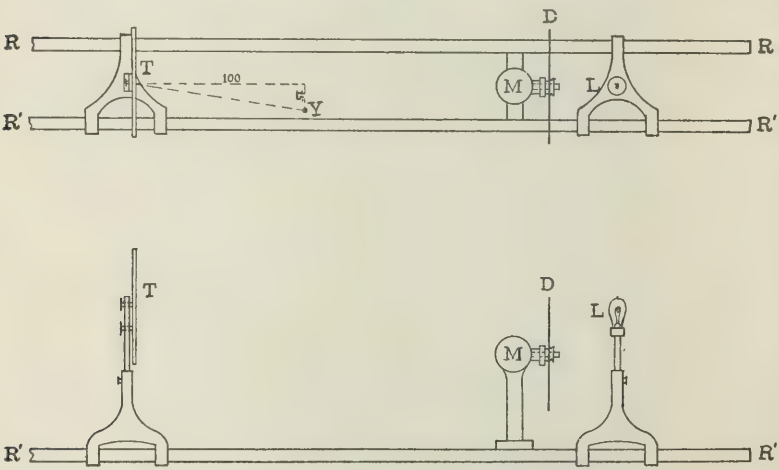

Fig. 1.—Plan and side elevation of photometer track used in flicker measurements.

A photometer track as indicated in Fig. 1, was set up in a photometer room with blackened walls, floor, and ceiling. An incandescent lamp L, of uniformly maintained, known horizontal candle-power, was supported in a fixed position at one end of the rails RR′. A flat screen or "target" T, was supported in a fixed position, and in a vertical plane, transverse to the track, at

[1] A paper read before the New England Section, February 13, 1911.

[2] See Bibliography appended.

a measured distance from the lamp. From these data, the illumination of the target was determined and recorded. In the research of 1907, the target was, at first, the grease-spot disk of an ordinary Bunsen photometer carriage, and later a white paper pad 20.3 cm. high by 13.3 cm. wide (8 by 5.25 in.).

Between the incandescent lamp L and the target T, and conveniently close to the former, an electric motor M, of the direct-current fan-motor type, was mounted on the track, with its shaft parallel to the same. A sector-disk D of varnished sheet steel was mounted on the shaft as seen in Figs. 2 and 3. The sector-

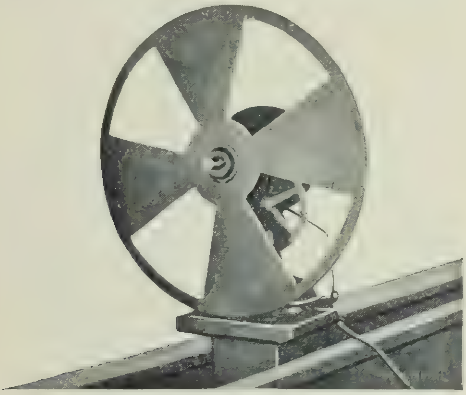

Fig. 2.—Four window sector-disk and driving motor.

disk may have any number of symmetrically disposed sectorial windows or apertures. Two-window, four-window and eight-window disks were used, at an electrically controlled speed, so as to illumine and darken the target alternately, as the windows passed before the lamp. Thus, with a four-window disk, there would be four complete flicker-cycles of illumination and darkness on the target for each revolution of the disk. With the motor shaft running very slowly, the illumination on the target flickered very violently; but as the speed increased, the flickering became less noticeable, until, at a certain critical speed, the flickering just vanished, and the target appeared to have a steady average illumination. This critical speed determines the frequency of flicker at which the flicker vanishes, or the vanishing-

flicker-frequency, for the particular observer, with the particular intensity of illumination, material, size, and color of the target, as well as its distance from the observer's eye. The wave-shape of the flicker cycle could also be changed by changing the angular width of the windows in the sector-disk, but no difference in vanishing-flicker-frequency could be detected with certainty resulting from such changes.

The magnitude of the vanishing-flicker-frequency is a measure of the sensitiveness of the eye to flicker under the particular set of conditions producing the stimulus. Under the same set of conditions, it varies somewhat between different individuals, per-

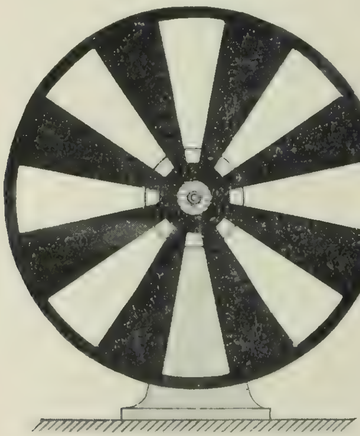

Fig. 3.—Eight-window sector-disk.

haps not only on account of different personal optical sensitiveness, but also on account of differences in personal estimates of what constitutes disappearance of flicker. It also seems to differ slightly, at different times, with one and the same individual. Ordinarily it can be measured with a fair degree of precision, different successive measurements varying only one or two per cent. from the mean value of all. Fatigue of the eye distinctly lowers the vanishing-flicker-frequency.

Twenty deductions were made from the results of the earlier research, and were specifically stated at the end of the paper in 1907, above mentioned. These deductions have been all sup-

ported and extended by the later experiments here described. The new experiments had two general purposes; namely:

First, to determine the influence of the size of the target on the vanishing-flicker-frequency, everything else being kept the same.

Second, to determine the effect of flicker on rotating targets, as distinguished from stationary targets.

Influence of the Size of the Target.—Five different sizes of circular disk targets, of the same white paper, were prepared. Their diameters were 4, 9, 16, 25, and 36 cm. respectively, or as the squares respectively of the numbers 2, 3, 4, 5, and 6. Their areas were thus respectively proportional to the fourth powers of those numbers. Each target was supported in a black frame from a tripod on the photometer track, as shown in Fig. 4, at a measured distance from the incandescent lamp. The observer's eye was stationed as nearly as possible at a point on a level with the center of the target, 100 cm. in front of it, and 15 cm. to the left of it, as indicated at Y, Fig. 1. The angle between the rays of light incident on the center of the target, and the rays returned from it to the eye, was thus approximately 8.5 degrees.

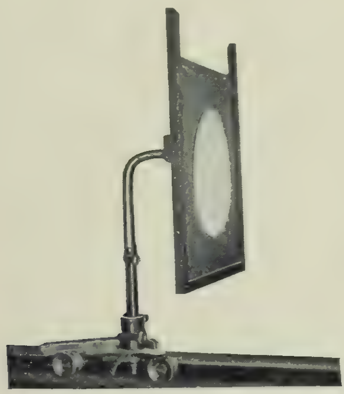

Fig. 4.—Target frame holder and carriage.

The carbon-filament incandescent lamp L, Fig. 1, was maintained at the constant luminous intensity of 50 international candles, with the aid of a separate voltmeter, by keeping it connected to the terminals of a storage-battery, through an adjust-

able rheostat. It consumed 139 watts. Measurements were made, at regular intervals, to check the intensity, by removing the target, and using a photometer head and standard lamp, in the usual way.

The speed of the sector-disk was measured by gearing a small auxiliary shaft to the motor shaft, with a velocity reduction of 10:1, and allowing a cam on the auxiliary shaft to strike a projecting wire audibly, once in each revolution. The number of such blows given by the cam in a certain number of seconds, taken with a stop-watch, indicated the frequency of flicker, directly, in cycles per second. The speed was also occasionally checked with a stroboscopic fork.[3] The target was first set at such a distance as would cause it to receive a predetermined illumination in millilumens per sq. cm. The observer's eye was placed at the proper point of observation. The speed of the sector-disk was then gradually raised until the observer just ceased to perceive the flicker. The speed of this disk was held at this point, measured, and recorded. The target was then shifted so as to obtain the next desired illumination, the new vanishing-flicker-frequency measured, and so on, throughout a series. The same series would then be successively repeated with different sizes of targets.

All luminous intensities reported in this paper, as measured in this research, are in international candle-power, as maintained at the Bureau of Standards since April 1909, with England and France. (1.11 Hefner).[4] Illuminations are expressed in international-candle-lumens per sq. cm., or the thousandth part thereof (millilumens per sq. cm.).[5]

[3] "The measurement of rotary speeds of dynamo machines by the stroboscopic fork," by A. E. Kennelly and S. E. Whiting, *Trans.* Am. Inst. El. Engrs., 27, 631-649.

[4] TRANSACTIONS of the Illuminating Engineering Society, 4, No. 7, Oct., 1909, p. 527.

[5] The rational systematic unit of illumination is 1 international-candle-lumen per sq. cm., or the illumination produced by 1 candle at 1 cm. This is, however, a very intense illumination, and a more convenient practical unitary value is the thousandth part thereof or 1 millilumen per sq. cm., corresponding to that produced by 1 candle at $\sqrt{1000}$ cm. = 31.62 cm. This is, for rough purposes, the same as the foot-candle (1 candle at 30.48 cm.). In fact, 1 foot-candle is a stronger illumination than the millilumen-per-sq. cm. in the ratio 1.0764. A millilumen-per-sq. cm. is also precisely equal to 10 meter-candles. Consequently m millilumens per sq. cm. = $\frac{m}{1.0764}$ foot-candles = 10 m meter-candles. All the illuminations enumerated in this paper are thus foot-candles, to a first approximation, and are also convertible into meter-candles by shifting the decimal point one place to the right.

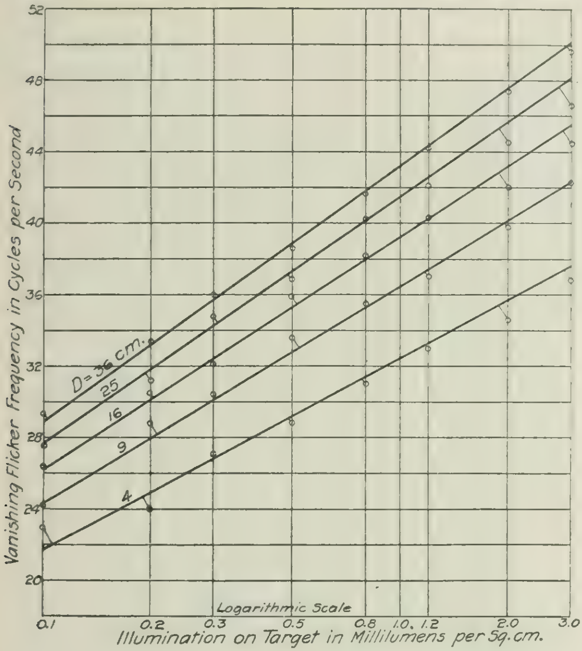

Fig. 5.—Effect of varying the size of target; Observer No. 1.

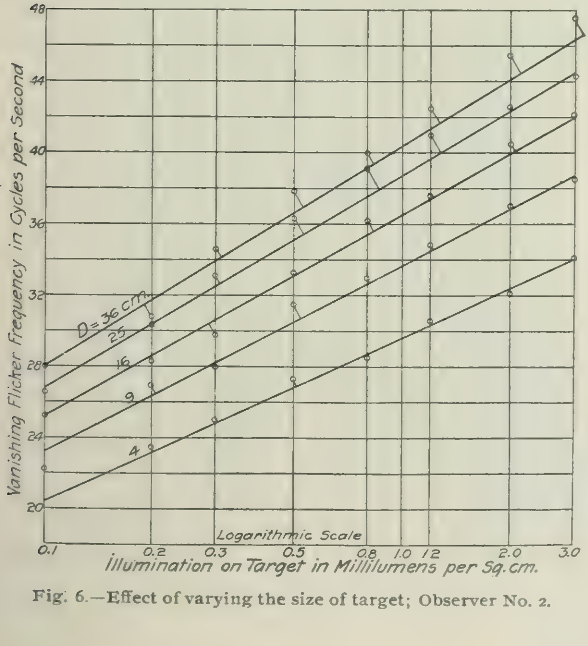

Fig. 6.—Effect of varying the size of target; Observer No. 2.

Figs. 5 and 6 show the vanishing-flicker-frequency with the different sizes of target and for varying intensities of incident illumination on the target at the "open-window" moments. The flicker-frequencies are plotted to ordinary uniform scale, as ordinates, against the common logarithms of the illumination intensities as abscissas. It will be seen that the graphs corresponding to the observations are all straight lines within the limits of observational error. Fig. 5 represents the observations of observer No. 1 and Fig. 6 the independent observations of observer No. 2.

In Tables I and II are collected the mean numerical values for observers 1 and 2 respectively, in accordance with Figs. 5 and 6.

TABLE I.—OBSERVATIONS OF FLICKER-FREQUENCY BY OBSERVER NO. 1.

Calculations by the formula: $n = 1.9(4.6 + \log_{10}S)(6.0 + \log_{10}E)$.

Target illumination. Millilumens per sq. cm.	D = 4 cm. S = 12.57 cm.²		D = 9 cm. S = 63.6 cm.²		D = 16 cm. S = 201.1 cm.²		D = 25 cm. S = 490.9 cm.²		D = 36 cm. S = 1018 cm.²	
	Obsd.	Cal.	Obsd.	Cal.	Obsd.	Cal.	Obsd.	Cal.	Obsd.	Cal.
0.1	23.0	21.7	24.2	24.3	28.4	26.2	28.6	27.7	29.3	28.9
0.2	24.0	24.9	28.8	28.0	30.5	30.2	31.2	31.9	33.4	33.3
0.3	27.1	26.8	30.4	30.1	32.1	32.5	34.8	34.3	36.0	35.8
0.5	28.8	29.3	33.6	32.8	35.9	35.4	36.9	37.3	38.6	39.0
0.8	31.0	31.4	35.5	35.3	38.2	38.1	40.2	40.2	41.7	41.9
1.2	33.0	33.3	37.0	37.5	40.3	40.4	42.1	42.6	44.2	44.5
2.0	34.6	35.7	39.8	40.2	42.0	43.3	44.5	45.7	47.4	47.7
3.0	36.8	37.6	42.5	42.3	44.5	45.6	46.6	48.2	49.6	50.2

TABLE II.—OBSERVATION OF FLICKER-FREQUENCY BY OBSERVER NO. 2.

Calculations by the formula: $n = 1.785(4.02 + \log_{10}S)(6.23 + \log_{10}E)$.

Target illumination. Millilumens per sq. cm.	D = 4 cm. S = 12.57 cm.²		D = 9 cm. S = 63.6 cm.²		D = 16 cm. S = 201.1 cm.²		D = 25 cm. S = 490.9 cm.²		D = 36 cm. S = 1018 cm.²	
	Obsd.	Cal.	Obsd.	Cal.	Obsd.	Cal.	Obsd.	Cal.	Obsd.	Cal.
0.1	22.2	20.4	25.1	23.2	26.5	25.2	28.0	26.8	28.0	28.0
0.2	23.5	23.2	26.9	26.4	28.3	28.7	30.3	30.4	30.8	31.8
0.3	25.0	24.8	28.0	28.2	29.8	30.6	33.1	32.5	34.6	34.0
0.5	27.3	26.8	31.5	30.5	33.3	33.4	36.3	35.2	37.9	36.8
0.8	28.5	28.7	33.0	32.6	36.2	35.4	39.1	27.7	40.0	39.3
1.2	30.6	30.3	34.9	34.4	37.6	37.4	41.0	39.7	42.5	41.5
2.0	32.1	32.3	37.0	36.7	40.5	39.9	42.6	42.5	45.5	44.3
3.0	34.1	34.0	38.5	38.6	42.1	41.9	44.2	44.5	47.6	46.5

Table III gives the particulars of the five targets.

TABLE III.—PARTICULARS OF TARGETS.

Target No.	Diameter D, cm.	Illuminated area, S, cm.	$\mathrm{Log}_{10}S$	Solid angle subtended steradian Σ	$\mathrm{Log}_{10}\Sigma$
1	4	12.57	1.0993	0.00122	$\bar{3}.0864$
2	9	63.6	1.8035	0.00615	$\bar{3}.7890$
3	16	201.1	2.3034	0.01945	$\bar{2}.2889$
4	25	490.9	2.6910	0.04745	$\bar{2}.6762$
5	36	1,017.9	3.0077	0.09770	$\bar{2}.9899$

It will be seen that the slopes of the straight lines in either Fig. 5 or Fig. 6 increase from the lowest to the highest. That is, in the general equation of this family of graphs:

$$n = p + q \log_{10} E, \qquad \text{cycles per second,} \quad (1)$$

where n is the vanishing flicker-frequency, E the open-window

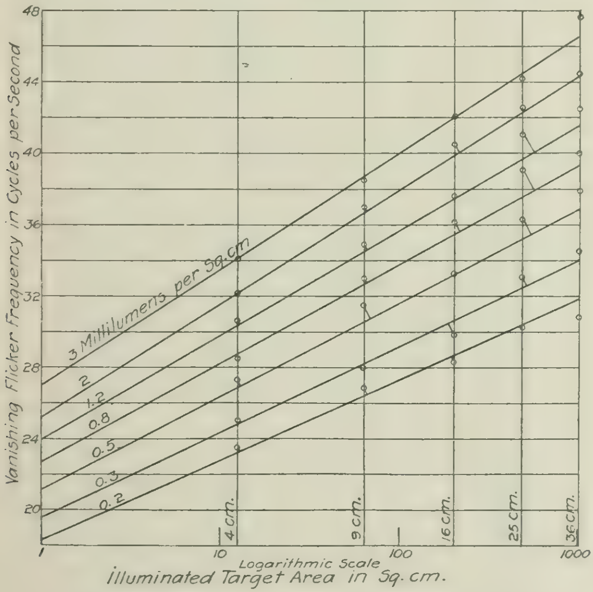

Fig. 7.—Effect of varying the illumination density.

illumination, or maximum cyclic illumination on the target, in lumens per sq. cm., p and q are constants for one and the same target. Both p and q increase, however, as the size of the target is increased.

In Fig. 7, the observations contained in Table II are presented

graphically to ordinates of vanishing-flicker-frequency on the ordinary scale, and abscissas of target area on logarithmic scale, with different intensities of illumination. Here again, the graphs may be considered as approximately straight lines which increase both in their elevation, and in their slope, as the illumination increases. That is, in the general equations of the graphs in Fig. 7:

$$n = r + s \log_{10} S, \qquad \text{cycles per second,} \quad (2)$$

where S is the area of the illuminated surface of the target in sq. cm. and r, s, constants for one and the same size of target. These constants increase when the target illumination is increased.

Equations (1) and (2) may be satisfied by the relation:—

$$n = a \log_{10} (tS) . \log_{10} (uE), \text{ cycles per second,} \quad (3)$$

$$= a\,(b + \log_{10} S)\,(c + \log_{10} E) \quad (4)$$

where t, u, a, b, and c, are constants throughout the series. The observations of observer No. 1 appear to be fairly well satisfied by:—

$$a = 1.9,\ b = 4.6,\ c = 6.0 \ or:$$

$$n_1 = 1.9\,(4.6 + \log_{10} S)\,(6.0 + \log_{10} E), \text{ cycles per second,} \quad (5)$$

between the limits $S = 12.6$ and 1,018 sq. cm., $E = 10^{-4}$ and 30×10^{-4} lumens per sq. cm. while those of observer No. 2 appear to be fairly well satisfied by:—

$$a = 1.785,\ b = 4.02,\ c = 6.23; \text{ or:—}$$

$$n_2 = 1.785\,(4.02 + \log_{10} S)\,(6.23 + \log_{10} E), \text{ cycles per second,} \quad (6)$$

In Tables I and II the values computed by (3) and (4), respectively, are grouped beside the observations, for comparison.

It was observed during the tests that, for a given illumination on the target, the vanishing flicker-frequency depended only on the ratio of the target diameter to target distance from the observer's eye, provided this ratio did not exceed 0.36. That is, a 16-cm. target disk at a distance of 100 cm. from the eye produced the same vanishing flicker-frequency as a 8-cm. target at a distance of 50 cm. This is easily understood because the brightness of the image formed on the retina directed to a bright object should be the same for all distances away from the object, if the

iris diaphragm has the same aperture, and the size of the image on the retina depends only on the solid angle subtended by the object at the optical center of the eye. Consequently, the retinal image of a 16-cm. disk at 100 cm. should be as large and as bright as that of a 8-cm. disk at 50 cm., if the illumination on the disks is the same, and if the iris diaphragm aperture is the same. Therefore, all target dimensions may advantageously be referred to their solid angular dimensions, in comparing different targets. If the target disk area in sq. cm. be divided by the square of the distance of the target center from the optical center of the eye, (for practical purposes the optical center may be taken as the center, and in the plane, of the iris) there is obtained the solid angle subtended by the target at the eye, assuming that the plane of the target is perpendicular to the line of sight directed to its center, and that the target radius is not more than 20 per cent. of the target distance. (See Appendix II.) In this case the square of the distance from the eye was 10,225 cm^2; so that the solid angle subtended by each target was nearly equal in steradians to $\frac{S \cos \theta}{10,225}$, as given in the fifth column of Table III. Consequently equation (4) leads to

$$n = a(B + \log_{10}\Sigma)(c + \log_{10}E), \qquad \text{cycles per second,} \quad (7)$$

where Σ is the solid angle subtended by the illumined target at the observer's eye in steradians, and B the corresponding general constant. In the case of observer No. 1, B becomes 8.613 and in that of observer No. 2, B becomes 8.033; so that using the solid angle Σ of the target in steradians, and the maximum cyclic illumination of the target in lumens per sq. cm., equation (5) and (6) become respectively:

$$n_1 = 1.9(8.613+\log_{10}\Sigma)(6.0+\log_{10}E), \qquad \text{cycles per second,} \quad (8)$$

$$n_2 = 1.785(8.033+\log_{10}\Sigma)(6.23+\log_{10}E), \text{ cycles per second,} \quad (9)$$

it being understood that the experimental observations range only from $\Sigma = 0.001$ to 0.1 steradian, and from $E = 0.0001$ to 0.003 lumens per sq. cm. (0.09 to 2.8 foot-candles, or 1 to 30 meter-candles).

As may be seen either from the preceding formulas, or from the graphs of Figs. 6 and 7, the increment in vanishing flicker,

produced by a given percentage increase in target area or solid angle, is much less than that produced by the same percentage increase in target illumination, under practical conditions. Thus, in Fig. 6, with the middle size of target—16 cm.—increasing the illumination to ten-fold adds 11.3 cycles to the flicker, and doubling the illumination adds 3.4 cycles. But in Fig. 7 with a middle illumination of 0.8 millilumens per sq. cm. (0.74 foot-candles or 8 meter-candles), increasing the target area in a ten-fold ratio adds only 5.6 cycles to the vanishing flicker-frequency, or doubling the area adds only 1.68 cycles. Judging from these facts, the sensibility of the observer's eye to flickering light was, under the above conditions, about twice as great in regard to the brightness of the target, as in regard to the solid angle it subtends. This is the more remarkable, because, at first thought, it might be supposed that the flicker sensation would be a simple function of the total quantity of light received by the eye from the target, or in proportion to the product of the illumination and solid angle of the target. In the observations here reported, however, such was not the case, as is shown by the greater influence on the vanishing flicker-frequency of doubling the illumination of the target, than of doubling its subtended solid angle. The same product SE, of surface S and illumination E, gave rise to markedly different vanishing flicker-frequencies. Thus, in the case of observer No. 1, as indicated in Fig. 5:

The 36-cm. target at 0.1 millilumen per sq. cm. would give 29.0 cycles.
The 25-cm. target at 0.208 millilumen per sq. cm. would give 31.9 cycles.
The 16-cm. target at 0.506 millilumen per sq. cm. would give 35.5 cycles.
The 9-cm. target at 1.6 millilumen per sq. cm. would give 39.0 cycles.

In each of the above combinations, the product SE was the same, or 0.10 lumen, this being the light falling on the target. The total light reaching the cornea of the eye, from the target, would also be approximately the same in each combination.

A wide field lies open for investigation in this direction, in order to ascertain the relative visual sensibilities of different persons to change in the solid angle, and in the brightness, of flickered targets. In measurements of vanishing flicker-frequency by different observers, under constant target solid-angle, it is always a matter of doubt how far the differences may lie in

the intellectual estimate of what precisely constitutes vanishing flicker. But when measurements are made, as above described, first with the solid-angle varied at constant illumination, and then with the illumination varied at constant solid angle, the same intellectual estimate enters both series of measures, and the proportionate influence of a given increase-ratio of illumination, to that of the same increase-ratio in solid angle, is a personal characteristic of the observer, for the particular initial values of solid angle and illumination selected.

Illumination—Solid-Angle Increment-Ratio. Thus, commencing at a solid angle Σ, and illumination E, of the target, if the vanishing flicker-frequency obeys formula (7), a f-fold ratio of increase in E, with Σ constant, will produce in n an increase of:

$$\Delta n_\Sigma = a(B + \log_{10}\Sigma)\log_{10} f, \qquad \text{cycles per second,} \quad (10)$$

while a f-fold ratio of increase in Σ, with E constant, will produce in n an increase of:

$$\Delta n_E = a(c + \log_{10}E)\log_{10} f, \qquad \text{cycles per second,} \quad (11)$$

Consequently, the ratio of the two increases will be:—

$$r = \frac{\Delta n_\Sigma}{\Delta n_E} = \frac{B + \log_{10}\Sigma}{c + \log_{10}E} \qquad \text{numeric.} \quad (12)$$

Thus, taking the good reading illumination of 2 millilumens per sq. cm. (1.86 foot-candles, or 20 meter-candles) in the measures above reported, and the solid-angle of 0.01945 steradian subtended by the 16-cm. target, the illumination-solid-angle increment-ratio r_1 for observer 1 was by (8)

$$r_1 = \frac{8.613 + \bar{2}.289}{6.0 + \bar{3}.301} = \frac{6.902}{3.301} = 2.09 \qquad (13)$$

and r_2 for observer 2 was by (9)

$$r_2 = \frac{8.033 + \bar{2}.289}{6.23 + \bar{3}.301} = \frac{6.322}{3.531} = 1.79. \qquad (14)$$

The two observers differed, therefore, in this ratio appreciably.

Sensitiveness of the Retina to Flicker at different distances from the Fovea.—It had been noticed, both in the earlier and later research, that after the speed of the sector-disk D (Fig. 1) had been raised until the flicker appeared to vanish from the target, the flicker could often be faintly revived by moving the

eye from the center to the edge of the target. This suggested the possibility of a lesser sensibility to flicker existing at the fovea centralis than in the regions of the retina surrounding it. In order to test this possibility, a series of annular targets was constructed, each with a black circular center. The white annular surface area surrounding the black center was in each case made the same as that of a plain 16-cm. white disk (201 sq. cm.) Table IV gives the particulars of these annular targets:

TABLE IV.—PARTICULARS RELATING TO WHITE ANNULAR TARGETS WITH BLACK CENTERS.

No.	Diameter of central black spot, cm.	Area of central black spot, sq. cm.	Solid angle subtended by black spot, steradians	Diam. of whole target, cm.	Area of whole target, sq. cm.	Solid angle subtended by whole target steradian	Annular white surface area sq. cm.	Solid angle subtended by white surface steradians	Vanishing flicker frequency. Cycles per second
1	0	0.0	0.0	16.0	201.1	0.01945	201.1	0.01945	42.0
2	4	12.6	0.00122	16.5	213.7	0.02067	201.1	0.01945	40.6
3	8	50.3	0.00487	18.25	251.4	0.02432	201.1	0.01945	36.7
4	12	113.1	0.01094	20.0	314.2	0.03039	201.1	0.01945	34.1
5	16	201.1	0.01945	22.6	402.2	0.03891	201.1	0.01945	33.4

The annular targets were all set up in succession under a maximum cyclic illumination of 2.5 millilumens per sq. cm. (2.32 foot-candles, 25 meter-candles) and the vanishing flicker-frequency with each, at the distance from the eye as indicated in Fig. 1, was as recorded in the last column of Table IV. The eyes were in each of these measurements directed to the center of the target. The solid angle subtended at the eye by the target as a whole varied from 0.019 to 0.039 steradian; but the solid angle subtended by the white surface remained substantially constant at 0.01945 steradian throughout. It will be seen that the vanishing flicker-frequency diminished steadily as the illuminated area on the retina was carried further from the optical center. This experiment seems to show that although retinal sensibility to flicker extends to a considerable distance from the fovea centralis; yet the sensitiveness is greatest at or near the fovea.

It is possible that the partial reappearance of flicker on a plain white target, when the eye is suddenly changed in direction from the center to the edge, may be due, either to fatigue of the retina near the fovea, or to the aid of momentary flicker due to the

motion of the eye; that is, to the introduction of a temporary moving-image flicker stimulus.

Stationary Colored Targets.—Two series of measurements were made of vanishing flicker-frequency with one size of target disk (25 cm. diameter) and different colors. One series was made with the unaltered light from a 50-c-p. carbon filament incandescent lamp operating at a specific consumption of 2.8 watts per candle and a set of 25-cm. disks of different colors, each subtending a solid angle of approximately 0.047 steradian. The other series was made with a single white 25-cm. disk, but with

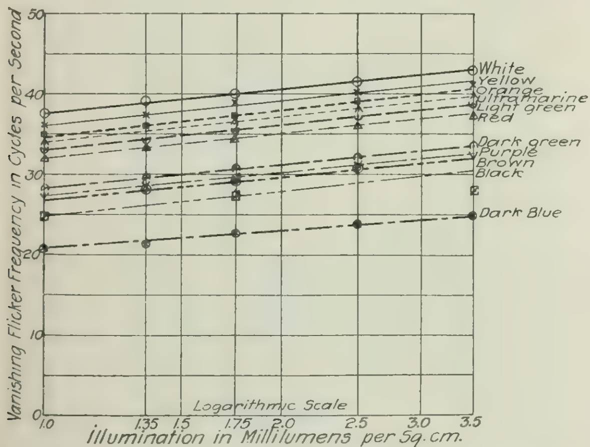

Fig. 8.—Effect of flickering white light on colored targets, 25 cm. in diameter.

colored glass screens between the lamp and the sector-disk, so as to produce the flicker in colored light.

The results of the above series of measurements are shown for observer No. 2 in Figs. 8 and 9 respectively. It will be seen that in both, the vanishing flicker-frequency with white is higher than with any single color, and that yellow comes next to white in order. The exact order of the colors is not worth discussing at length, since the exact color tints were not measured, and consequently are indefinite. The lines in Figs. 8 and 9 are however approximately parallel, and the mean increment of frequency with doubled illumination is 3.5 cycles per second. In Fig. 8, dark blue appears to be distinctly below black in stimulating

flicker sensation. The "black" target used in this case, however, reflected an appreciable amount of light.

Influence of Eye Fatigue on Vanishing Flicker-Frequency.—At the conclusion of the series of measurements given in Fig. 8, which commenced with the white target, and which lasted three hours, the observations were repeated with the white target, to determine the effect of eye fatigue on vanishing flicker-frequency.

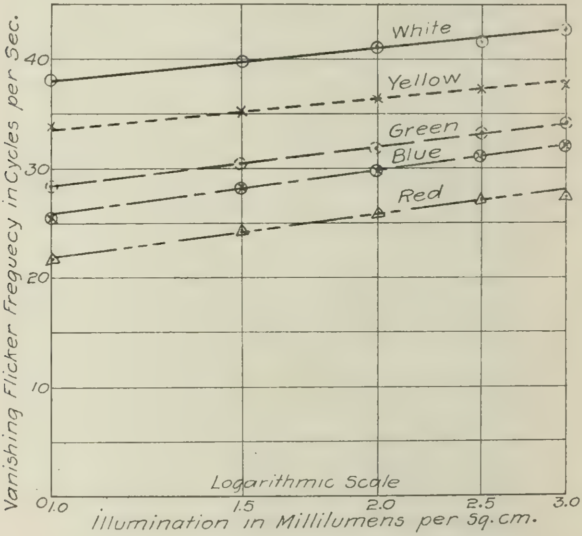

Fig. 9.—Effect of flickered colored light on white target.

The readings showed a fairly uniform reduction of four cycles per second over the range of illuminations in Fig. 8.

FLICKER ON MOVING TARGETS.

Flicker on moving targets may be divided into two classes:—namely,

First, that in which the moving object, illumined by flickering light, pursues, or at least apparently pursues, a non-reentrant path.

Second, that in which it pursues a reentrant path or closed loop.

An example of the first case is found when a brief succession

of electric-discharge flashes illumines an object rapidly moving in one direction, as the cross-head of a reciprocating piston rod; or when a brass rod is waved rapidly in one direction beneath an alternating-current arc lamp. In such a case, an image of the moving object is seen in a number of separate and successive positions, and the successive images, with the eye at rest, are not superposed. An example of the second case is when a revolving wheel is viewed by rythmically flickering light, such as that from an alternating-current arc-lamp. In such a case the successive images may be superposed. Only the second class of flicker, on moving targets, was investigated in this research.

The first target used consisted of a white cardboard disk, 15 cm. in diameter, mounted on the shaft of a small direct-current motor, as shown in Fig. 10. The speed of this motor, which

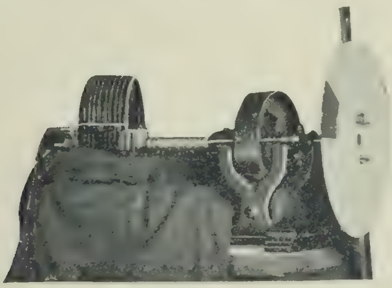

Fig. 10.—Single-spot rotating target with driving motor and speed-indicating magnetic-generator.

was electrically controlled, was measured by connecting a voltmeter to the terminals of a small magneto machine on the same shaft. A single sectorial black spot 45° wide, and 2.5 cm. deep, was painted on the target, as shown at A in Fig. 11. The target was supported at a distance of 250 cm. from the lamp, in front of which was placed a motor driven sector-disk of four windows, as in the previous experiments. If, with the sector-disk speed and flicker-frequency constant, the target was watched at rest, there was the usual stationary-target flicker on its surface; but when the target was set in rotation at a constant convenient speed, and the sector-disk was rotated at an increasing speed, a number of stroboscopic images presented themselves successively, according to well-known principles. First one spot appeared stationary

in space as at 1, Fig. 11, then two at opposite ends of target diameter, as at 2; then three 120° apart as at 3, and so on. The edges of the spot images were, however, somewhat blurred and not so sharp as Fig. 11 suggests.

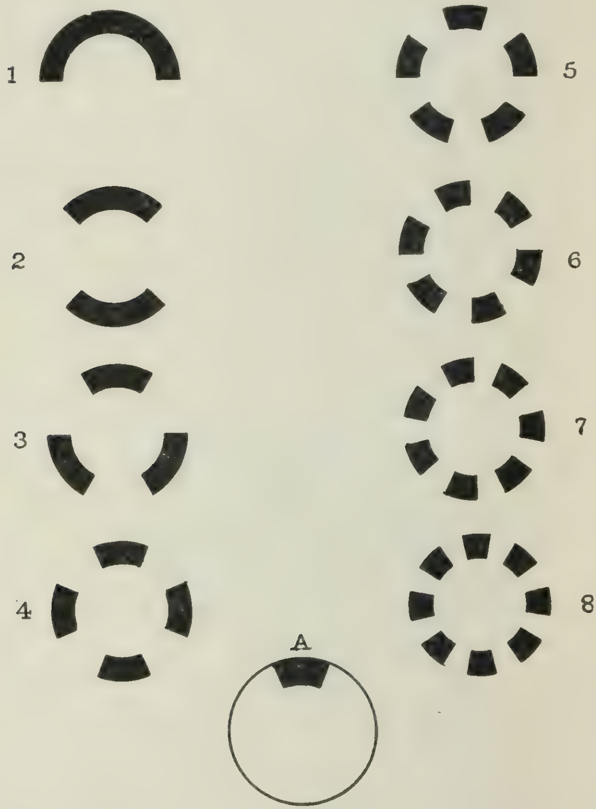

Fig. 11.—Multiple stroboscopic images formed on the one-spot rotating disk at successively increasing multiple speeds of the sector disk.

Laws of Stroboscopic Images Produced by Flicker on Rotating Targets.—If the speed of the target is T revolutions per second, that of the sector-disk D revolutions per second, and if there are g positions of spot-symmetry in one revolution of the target, the number of positions of spot-symmetry passed through by the target in one second of time will be Tg. Again, if the number

of symmetrically disposed windows in the sector-disk is w, the number of light admissions to the target per second will be:

$$n = Dw, \qquad \text{cycles per second, (15)}$$

which is also the frequency of flicker on the target. In order that a stationary single stroboscope image of the target may be formed on the retina, it is necessary that all of the admissions of light shall find the target in some position of spot-symmetry. This will happen with simple repetition or one-to-one coincidence if:

$$Tg = Dw, \qquad \text{cycles per second, (16)}$$

If, however, the target rotates faster than the disk and just moves through 2, 3, or k positions of symmetry to one window opening or illumination, the same image will be produced; so that a single image of the target will be found for the general condition:—

$$Tg = k.Dw = kn, \qquad \text{cycles per second, (17)}$$

where k is any integer. Again, if the disk moves faster than the target, and admits light to the target not only at successive positions of spot symmetry, but also at definite intermediate positions, the image of the target will still tend to appear stationary, but will be fainter and reduplicated, in each of the intermediate positions. This will happen if the speed of the target is ½, ⅓, ¼, or $1/k$th of the speed of the disk, that is for a multiple stroboscopic image,

$$Tg = \frac{Dw}{k} = \frac{n}{k}, \qquad \text{cycles per second, (18)}$$

where k is any integer, and is also the order of multiplicity of the image.

In the case of a 1-spot target, like that shown in Figs. 10 and 11, there is only one position of symmetry per revolution, so that $g = 1$, and with a four-window sector-disk, $w = 4$; consequently for a single image of the target (17) becomes:

$$T = 4k.D = kn, \qquad \text{revolutions per second, (19)}$$

and for a multiple image of k spots, (18) becomes:—

$$D = k.\frac{T}{4}, \qquad \text{revolutions per second, (20)}$$

$$n = k.T, \qquad \text{cycles per second. (21)}$$

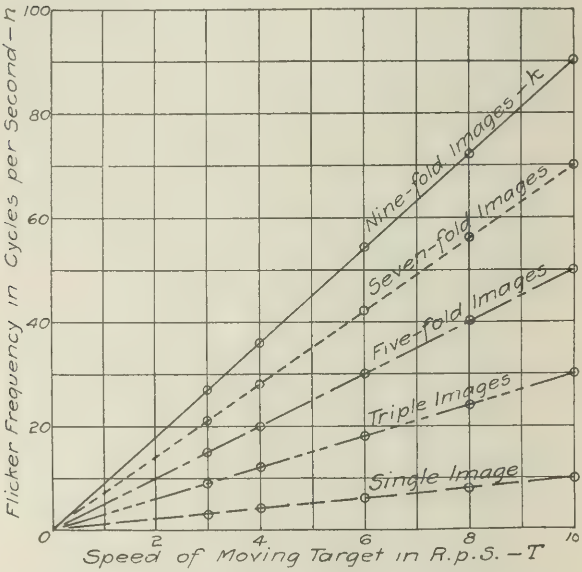

Fig. 12.—Stroboscopic effect with various multiple images.

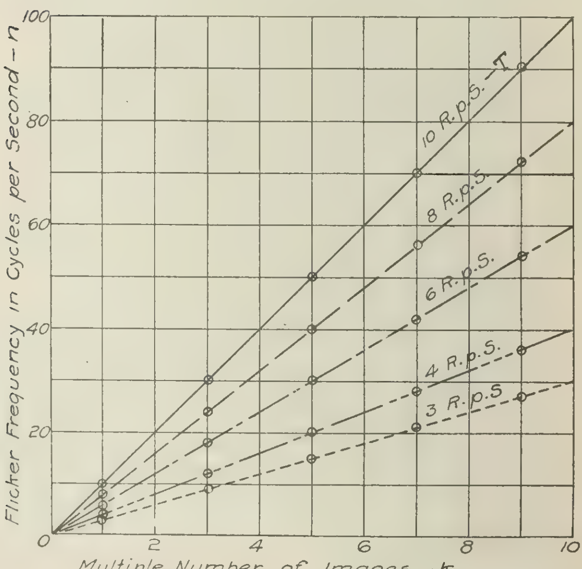

Fig. 13.—Stroboscopic effect with different constant speeds of moving target.

The relations expressed in formulas (17) to (21) were checked experimentally within the limits of speed observation errors, as shown in Figs. 12 and 13. Fig. 12 shows the flicker-frequency n, according to (21), as a function of the target speed T for various odd multiple images of the spot k (1, 3, 5, 7 and 9 of Fig. 11). Fig. 13 shows the flicker-frequency n as a function of k for different constant speeds T of the target, according to (21). The observations were all made with maximum cyclic illumination on the target of 0.8 millilumens per sq. cm. (0.74 foot-candle or 8 meter-candles) and with the target subtending at the eye a solid angle of approximately 0.0028 steradian.

Blendings and Flickering Appearances on Rotating Targets Between Successive Stationary Stroboscopic Images.—It was found that at any of the synchronous speeds defined by (18) or (20) the stroboscopic image on the target remained stationary in space. When the synchronism began to be departed from in one direction or the other, the image began correspondingly to rotate in one direction or the other. Thus, with the single-spot target making say four revolutions per second steadily, counter clockwise, if the four-window sector-disk made just one revolution per second counter-clockwise, so as to give four complete flicker cycles per second, the image of the target with its spot appeared stationary. If the disk speed dropped to ¾ rev. per sec. and the flicker frequency to 3 cycles per second, the image of the target rotated counter clockwise once per second; while if on the contrary the disk speed rose to 1¼ rev. per sec. and the flicker-frequency to 5 cycles per second, the image of the target rotated clockwise once per second. Still increasing the speed of the disk and flicker-frequency, the speed of the image would increase clockwise until the eye could not follow the rotation. The target image then presented an unsteady flickering appearance until the disk approached the next stationary stroboscopic speed, when the image of the target would reappear, rotating counter-clockwise. The speed of rotation of the new image would slacken, until the target would appear at rest with two spots, or doubled image, anon it would commence rotating clockwise, faster and faster until the rota-

tion could no longer be followed. The target would then present a hazy flickering appearance until the accelerating disk approached the next stroboscopic image speed, and so on. Thus between the successive stationary images there were intervals of flickering, and the frequencies at which these intermediate flicker-

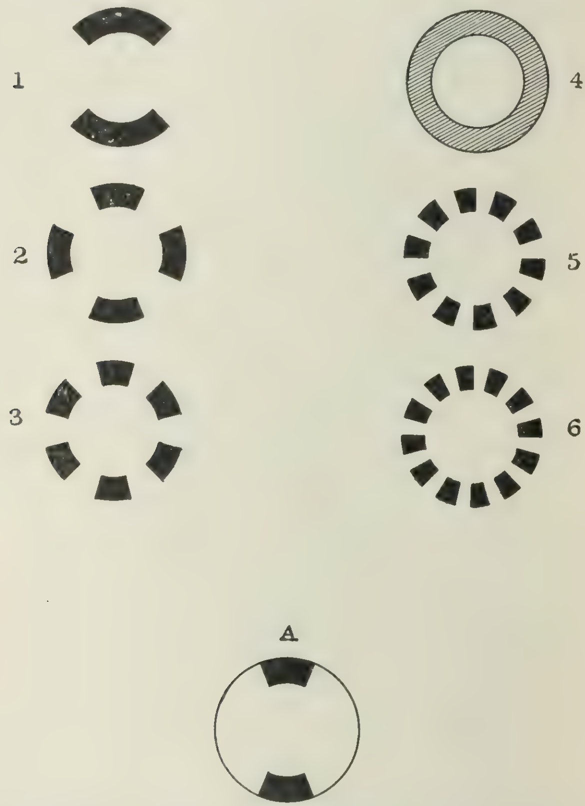

Fig. 14.—Multiple stroboscopic images formed on the two-spot rotating disk at successively increasing multiple speeds of the sector-disk

ings disappeared were noted as vanishing flicker-frequencies with rotating target. Beyond a certain number of multiple images (5 or 6), the intermediate flickering ceased to appear; so that the flickering could only be detected with certainty on the one-spot target up to the quadruple or quintuple stroboscopic image formation. Moreover, the flicker-frequency with the four-win-

dow sector-disk was not sufficient to make the flicker vanish completely between these lower orders of successive multiple images. The target was therefore exchanged for one which had two positions of symmetry per revolution, or two diametrically opposite spots, of 45° angular width and 2.5 cm. radial depth, as shown at A Fig. 14. The sector-disk was also exchanged for one of eight 22.5° windows, as shown in Fig. 3. Substituting therefore $g = 2$ and $w = 8$ in equation (18), there is obtained for a multiple image of the kth order, and of $2k$ spots:

$$n = 2kT, \qquad \text{cycles per second,} \quad (22)$$

A given flicker-frequency of incident light was thus obtained with half the disk speed previously needed, and, for a given number of spots in the image, at a quarter of the the disk speed previously needed.

The successive orders of multiple images obtained with constant target speed, and successively increasing sector-disk speed are indicated in Fig. 14 up to the sixth order, or that obtained with a flicker-frequency of 12 times the target revolutions per second. At the stroboscopic image of the fourth order, the appearance presented was not that of a stationary group of radial spots, but that of a uniform gray band. That is, for this particular speed, the individual spot images overlapped annularly in such a manner as to present no discontinuity of color around the resultant image.

Vanishing Flicker-Frequencies with Rotating Targets.—Observations were made of the frequency of flicker necessary to make the flicker on the rotating target disappear between successive stroboscopic stationary images. The illumination on the target was held at 1.8 millilumens per sq. cm. (1.67 foot-candles or 18 lux) and the solid angle subtended by the target at the observer's eye was approximately 0.022 steradian. The results are given in Table No. V.

The results are indicated graphically in Fig. 15. The observations in parentheses showed a slight residual flickering in an otherwise uniform grey band spot image of the target. In these cases, the frequency could not be raised to make the flickering disappear without starting the rotation of spots preceding the

TABLE V.—VANISHING FLICKER-FREQUENCIES OF INCIDENT LIGHT BETWEEN SUCCESSIVE STROBOSCOPIC MULTIPLE IMAGES.

Target speed	Observer No. 2 Between spot images				Observer No. 3 Between spot images			
r. p. s.	0-2	2-4	4-6	6-8	0-2	2-4	4-6	6-8
12.2	..	..	..	(100.0)	..	..	..	(97.5)
14.6	..	..	..	(114.2)	..	(44.4)	(75.5)	(117.6)
17.0	..	..	..	(129.0)	..	(50.0)	(93.1)	(133.3)
19.5	..	(63.5)	(103.9)	145.5	..	(57.1)	(102.5)	153.8
21.9	..	(70.1)	114.2	160.0	..	(65.6)	117.6	167.0
24.3	..	74.0	129.0	..	..	72.8	129.0	186.0
26.8	..	80.0	135.5	..	..	78.5	138.0	200.0
29.2	33.3	83.3	145.5	..	..	83.5	153.8	..
31.6	Flicker	88.9	151.0	..	(34.5)	91.0	160.0	..
34.0					33.3	97.5	166.5	.
36.4					32.0	100.0	182.0	.

next stationary stroboscopic image. The underscored observations represent true vanishing flicker-frequencies, while the readings in each column below the underscored values are smooth mergings between two successive orders of stroboscopic images, with no evidences of flicker. That is, they represent frequencies above the vanishing flicker point. The numbers above the underscored readings are therefore blends between successive stroboscopic images in which the frequency was below the vanishing point.

In Fig. 15, the critical vanishing flicker-frequency points as found by observer No. 2 are plotted with circles around them. The lines connecting blend points, when prolonged, appear to intersect at 20 cycles for zero target speed. No reliance can, however, be placed on this extrapolation.

Blends between successive stroboscopic images occurring to the left of the line A B Fig. 15 were accompanied by flicker. Blends occurring to the right of this line were devoid of flicker. Blends on or close to the line showed vanishing flicker-frequency.

It is to be noticed that the ordinates in Fig. 15 are cycles per second in the flicker of the light incident upon the target, and as determined from the number of window passages per second in the sector-disk. However, the frequency of flicker received on the retina will be the difference between the actual incident

frequency and that at which the last preceding stationary stroboscopic image was formed. Thus, taking observation marked 3 on Fig. 15 of 114.2 cycles per second at 21.9 revolutions per

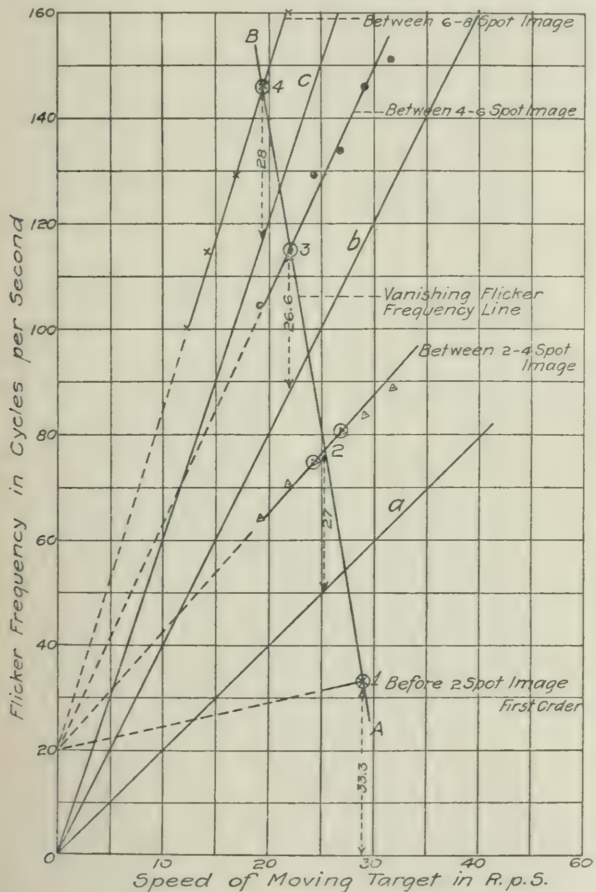

Fig. 15.—Vanishing flicker frequencies between the different consecutive stroboscopic images.

Curve a. Stationary stroboscopic image of first order; two spots.
Curve b. Stationary stroboscopic image of second order; four spots.
Curve c. Stationary stroboscopic image of third order; six spots.

second of the target, at this target speed, the stationary stroboscopic image of the second order with four spots would be produced by the frequency of 87.6 cycles per second. At 88.6 cycles the image would give one beat per second on the retina; at 89.6

cycles, two beats per second, and so on. Consequently, when the incident vanishing flicker-frequency in this case is noted at 114.2 cycles, it represents a retina vanishing flicker-frequency of 26.6 cycles as marked on Fig. 15. Thus observation 1 gives 33.3 cycles of retina frequency, No. 2 gives 27 cycles, No. 3, 26.6 cycles, and No. 4, 28 cycles. In this way, flicker on a rotating target may be set up at very high frequencies of incident light.

At observation 1 of 33.3 cycles, flicker was also just perceived on the central white portion of the target, corresponding in all essentials to flicker on a stationary white target, and in accordance with the observations in Fig. 6. In other words, the rotation of a uniform plain target does not change the vanishing-flicker-frequency measured with the same target at rest.

Vanishing Flicker-Frequencies on Rotating Target at Blends between Stroboscopic Images and different illuminations.—A series of observations was made of rotating-target flicker under different illuminations between 0.1 and 0.8 millilumens per sq. cm. (0.093 and 0.76 foot-candles, or 1 and 8 lux), the 25.4-cm. two-spot target rotating steadily at 24.3 revs. per sec., and subtending a solid angle of approximately 0.022 steradian. The measurements were made at the blend between the first and second order, and also at the blend between the second and third order of stroboscopic images. They are recorded in Table VI.

TABLE VI.—VANISHING FLICKER-FREQUENCIES ON TARGET AND ON RETINA.

Max cyclic target illumination, millilumens per sq. cm.	Observer No. 2				Observer No. 3			
	Target n 1-2	Retina n 1-2	Target n 2-3	Retina n 2-3	Target n 1-2	Retina n 1-2	Target n 2-3	Retina n 2-3
1.11	66.6	18.0	104.0	6.8	64.0	15.4	102.5	5.3
1.69	67.2	18.6	107.0	9.8	66.6	18.0	105.0	7.8
2.54	71.0	22.4	108.8	11.6	69.1	20.5	106.6	9.4
3.91	72.7	24.1	111.1	13.9	71.0	22.4	109.5	12.3
5.77	74.0	25.4	114.7	17.5	72.7	24.1	112.7	15.5
7.95	75.5	26.9	116.5	19.3	74.0	25.4	113.7	16.5

The heading n 1-2 signifies the vanishing-flicker-frequency at the blend occurring between the first and second order of stroboscopic images, and n 2-3 that between the second and third order. The heading "Target" signifies the observed flicker-

frequency on the target; while the heading "Retina," signifies the corresponding deduced lower flicker frequency produced on the retina.

The incident frequencies between stroboscopic images of the first and second order have to be reduced by 48.6 cycles, to give the corresponding inferred retinal flicker-frequencies, and those between the second and third orders by 97.2 cycles. The measurements of observer No. 2 are presented in Fig. 16. They correspond to straight lines on semi-log. paper within the limits of

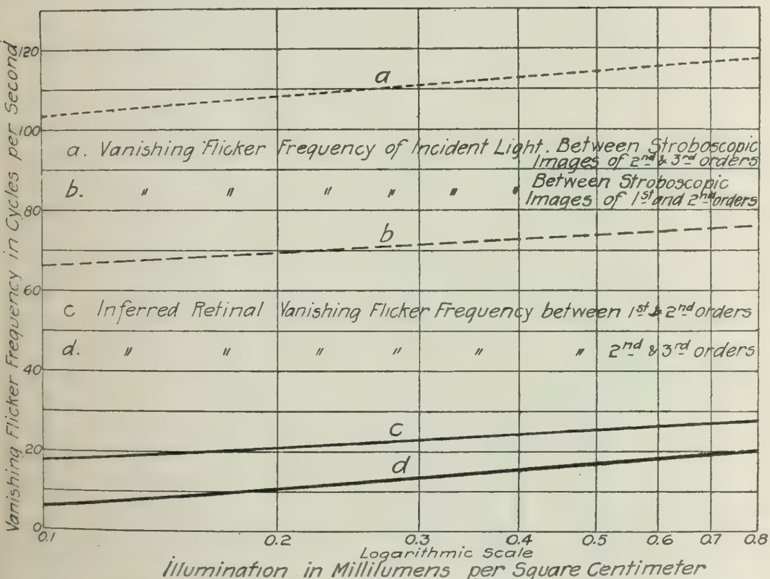

Fig. 16.—Lines of frequencies at which flickering between two consecutive stroboscopic images in different intensities of illumination on the moving target, seemed to vanish.

observational precision. The inferred retinal vanishing flicker-frequency for the blend between second and third orders is distinctly less than between the first and second orders. Measurements were not attempted below the first order of stroboscopic image, because, at the frequencies then involved, stationary flicker appeared on the white center of the target. They were not attempted above the third order, because, at the speed of the target selected, the incident flicker-frequency necessary to make the flicker vanish was difficult to reach.

Experiment on the effect of varying the Dimensions of the Target Spots.—It was found that varying the radial depth of the spots on the rotating target did not appreciably affect either the stroboscopic speeds or the vanishing flicker-frequencies at the blends. Similarly, varying the angular breadth of the spots had no appreciable effect.

CONCLUSIONS.

(1) The vanishing flicker-frequency for a stationary target depends upon the illumination of the target, its color and reflective quality, and on the solid angle subtended by the target at the observer's eye.

(2) Judging from the results obtained by a small number of observers, doubling the illumination on a stationary target, with other conditions unchanged, adds a certain increment to the vanishing flicker-frequency, and doubling the solid angle subtended by the target adds another and smaller increment. The ratio of the doubled-illumination increment to the doubled-solid-angle increment, under assigned initial conditions, seems to be a personal characteristic varying somewhat in different individuals.

(3) The sensitiveness of the retina to flicker appears to be greatest at or near the fovea centralis, and to diminish as this is departed from.

(4) The vanishing flicker-frequency is reduced by fatigue of the eye.

(5) On rotating targets, the effect of flicker is complicated by stroboscopic effects. The principal stroboscopic effects follow simple and well-known laws.

(6) In passing from one stroboscopic stationary image to the next in order, a blend is traversed, in which flickering may occur. The vanishing flicker-frequency found in such blends follow laws similar to those found with stationary targets, after allowing for the difference between incident flicker and retinal flicker.

(7) The vanishing flicker-frequencies with rotating targets were not perceptibly affected by changing either the angular width of the spots or the diametrical distance between them.

APPENDIX I.—List of Symbols Employed.

a, b, c, p, q, r, s, t, u, constants in different formulas for vanishing flicker-frequency.

D. Rotary speed of sector-disk (revs. per. sec.).

E. Illumination of a target (lumens per sq. cm.).

f. Ratio of increase in either illumination or solid angle (numeric).

g. Number of positions of symmetry in one revolution of a target, or the number of spots symmetrically placed on the same (numeric).

k. Any integer.

m. Illumination in millilumens per sq. cm.

n, n_1, n_2. Vanishing flicker-frequency, and for observers 1 and 2 (cycles per second).

Δn_Σ. Increment in n with Σ constant. (Cycles per second.)

Δn_E. Increment in n with E constant. (Cycles per second.)

S. Surface of target, (sq. cm.).

Σ. Solid angle subtended by target at observer's eye. (Steradians.)

r, r_1, r_2. Ratio of increments in n due to illumination and solid angle respectively, for observers 1 and 2, (numeric).

T. Rotary speed of target (revs. per sec.).

w. Number of windows in sector-disk.

APPENDIX II.—To Find the Solid Angle Subtended at the Observer's Eye by a Circular Target which Nearly Faces the Observer.

Let T T′, Fig. 17, be the projection on a horizontal plane *d b e* of a circular target of radius r cm., whose center is at A, and whose normal A N does not quite pass through the observer's eye at O; but makes with the line AO a small angle θ. It is required to find the solid angle subtended by the target, in this position, at the observer's eye O.

Assume that the target T T′ is rotated about its center A through the angle θ, into the position $t\ t'$, so as to bring its normal AN into coincidence with the line of sight AO. The projection of the target in the vertical plane will then be the circle PP′ of radius r cm. Let a sphere $tt'eb$ be drawn in space, with its center O at the center of the iris diaphragm of the observer's eye. Strictly speaking, therefore, the observer must be supposed to look at the target with one eye only; but if the radius R = Oe of the sphere of observation $t\ e\ b$ is large in comparison with the target radius r, the error involved by using either, or both, eyes will be small. The semi-visual angle of the target $\alpha = \sin^{-1}\frac{At}{tO}$, is the circular angle subtended at O by the radius of the target.

The solid angle subtended by the target tt' at O will be $\Sigma' = \frac{S'}{R^2}$

steradians where S′ is the surface of the sphere covered by the target. This is easily shown to be.

$$\Sigma' = \frac{v}{R} \cdot 2\pi, \qquad \text{steradians.}$$

Where v is the distance *Ad* from the center of the target plane to the sphere of observation behind, but

$$\frac{v}{R} = 1 - \cos\alpha = \text{vers}\,\alpha, \qquad \text{numeric;}$$

$$\Sigma' = 2\pi \text{ vers}\,\alpha, \qquad \text{steradians,}$$

or the solid angle is 2π times the versine of the semi-visual angle.

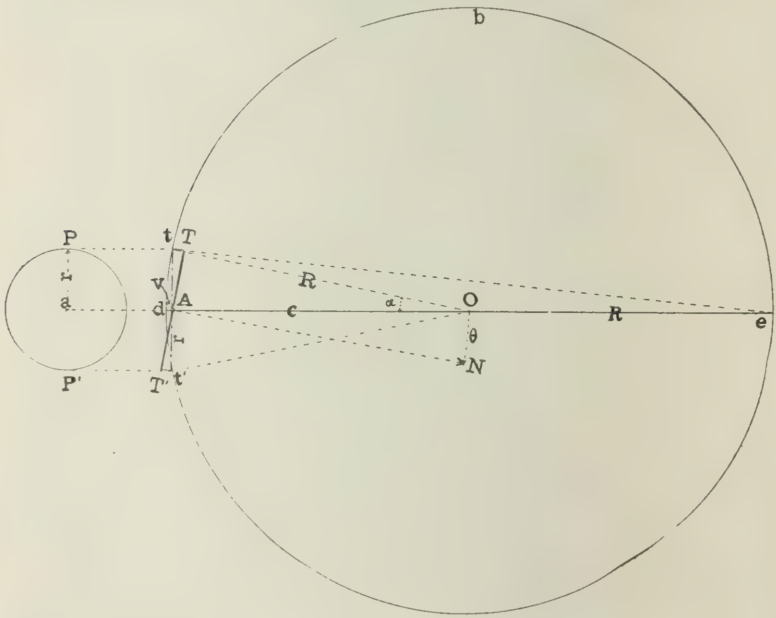

Fig. 17.—Diagram showing the solid angle subtended by a circular target at a given point.

This is the solid angle subtended by the target in the second position tAt', when it faces the observer. If the target be now returned to its original position TAT′, by rotation through the angle θ, the solid angle will be diminished in the ratio cos θ, provided that the angle θ is small and that R is large compared with r; so that the angle α is not materially changed by the deflection. Consequently the solid angle subtended originally by the target in the position TAT′ is

$$\Sigma = 2\pi . \text{vers}\,\alpha . \cos\theta, \qquad \text{steradians.}$$

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PHYSIOLOGICAL POINTS BEARING ON GLARE.[1]

BY PERCY W. COBB.

It is not without a great deal of apprehension that the author approaches the subject of "glare" in this paper. Indeed he confesses that he does not do much more than approach it. The bare title of "Glare" seems too comprehensive and explicit in view of the state of knowledge on the subject, and for that reason the title "Physiological Points Bearing on Glare" was chosen. Even so, in the title something had to be sacrificed for the sake of brevity, and it may be well to explain here, that the discussion may often trespass on the domain of psychology.

The word "glare" is one only recently adopted—if it can be said to have been adopted—by the engineering profession from general usage. Violence to its accepted meaning can not then be done by restricting its application to any one well defined physical or physiological phenomenon because that may seem scientifically clear to us in the present state of knowledge. Rather must one look to the meaning of the word as generally accepted and from that standpoint see how scientific facts and hypotheses relate themselves to it.

This plan, then, the present paper will follow. In view of the fact that detailed knowledge on the subject is scarce there will be much in it that is speculation, but it is hoped to reach at the end at least one point, more or less important, which has been fairly well and definitely worked out.

"Glare" means "a dazzling light," or (as a verb) "to shine with a bright, dazzling light." Dazzle (verb) means "to confuse the sight of by brilliance of light" or "to bewilder or surprise with brilliancy or display of any kind."

Without difficulty these meanings may be dressed in physiological terms, and it may be said that glare is "discomfort or depression of visual functions associated with strong light sensation." When so defined, glare has many phases. A well known fact points the way to a primary division of these conditions into two classes. This fact is that a general il-

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, January 12, 1911.

lumination of a given intensity may in one state of the eyes (as after an hour in absolute darkness) be uncomfortably bright, and a few minutes later be perfectly comfortable. This leads to a first question, namely, "At what intensity, if at all, does general illumination become too great?" One can scarcely conceive this as occurring (in anything but exceptional cases) under artificial illumination, and the example selected shall therefore be the case of sunlight or bright daylight out of doors. This again is usually well borne by the eyes, so that after all, too great *general* brightness of the field of vision is a relative condition—relative to the state of the eyes. For example, daylight out of doors may be painfully bright to persons suffering from certain eye troubles. Again, everyone, on emerging from a dark place will find that the daylight is too bright for a short time. After a brief period, however, adaptation has taken place, and the brightest daylight is accepted as a normal condtion. A small class of exceptions must be made to this statement. Bright daylight with snow on the ground, especially in high altitudes, can be persistently too bright, and special protection to the eyes may be needed. It may finally be said, then, that an absolutely too high general illumination is a thing that except under a few unusual conditions involving daylight or sunlight never takes place.

There is then the alternative to consider, the relative overbrightness of parts of the visual field, which is the only external condition to which one can properly attach the idea of glare. If it is desired to discriminate the various factors which contribute to this effect note must be made of differences which are conditioned in the first place not by absolute intensities or intrinsic brilliancies but by physiological and psychological limitations. If it be assumed that no light source is visible and that no part of the field is so bright as to cause demonstrable disturbance in the eye itself, there can still be such a distribution of light as to be irritating or depressing. It might be said that man prefers to have the upper parts of his visual field relatively dark. This corresponds to the ordinary daylight house illumination. The light falls on the lower part of the room, the ceiling is relatively dark, the furniture and other objects in the room well lit. In artificial illumination, the same

conditions—that is, a fair, moderately diffused illumination, with a downward preponderance—give a feeling of comfort and cheer to those entering and using the room.

Again, in going out of doors by daylight, one gets rid of the high luminosity of the topmost part of his visual field by the use of head gear provided with suitable brim or visor. This is true of women as well as men, except when the dictates of fashion forbid it.

Whether it be an inherent preference, or one derived from habit and association or one depending on physiological expediency (for instance, the fact that most objects that we wish to see closely do not project far above our horizon) it is still a general fact that illumination chiefly below and extending a moderate distance above the horizon is the one most generally preferred.

If the conditions are reversed, "glare" begins to be felt. This must then be enumerated as one of the conditions lying within the make-up of man on which glare depends. Since in this case of mental disturbance by wrong distribution of light, not physiologically over bright, there is no known corresponding disturbance of organ or tissue, the disturbance is provisionally called a "psychological" one.

One step nearer to a physiological disturbance, is a disturbance which may well be assumed to take place when a light source is in the field of view. To make this understood it is well to say a few words about the eye-muscles. These are twelve in number, six for each eye, and have the function of turning the eyeball so that its axis may point (within limits) in any direction. To see fine detail it is necessary that the image of the object of vision fall on a very limited portion of the retina known as the fovea, specialized for distinct vision. This happens when a person looks directly at an object. This obviously must happen alike for both eyes wherever the object is, so that the object of direct vision always falls on the fovea of each eye. The result is that images of other objects not directly looked at will fall on corresponding points of the two retinas. Now the difficult task is thrown on these twelve muscles of accurately placing the images in the two eyes on corresponding points of the two retinas, whether the object be far or near, up or down

or off at one side, and with this the eyes must be suitably accommodated so that they may be focussed alike and accurately converged with their axes meeting at the object of direct vision.

So perfectly do these muscles perform this adjustment, without the least knowledge of the fact on the part of the subject, that when the image in one eye is displaced by holding a prism of three or four degrees deflection before the eye, the muscles at once make adjustment for this, and the only knowledge of it is the disagreeable "pull" felt in the eye as the muscles assume the unusual strain.

It is perhaps needless to say more, to make it evident that we have to do here with a most complicated and delicately balanced set of muscles and nervous connections that could well be conceived, and that a small but persistent disturbing circumstance may work not only great discomfort but in extreme cases cause such confusion of the various eye movements as to make vision well-nigh impossible, and further, that the victim of all this disturbance will not have the slightest knowledge of how it all came about.

How are these facts to be connected with the conception of "glare?" One can say that a light source in the field of vision like a loud sound, or a sharp stimulus to the skin, or a severe pain, tends to capture the attention. When once attention has fastened itself upon a visual object the tendency is very strong to turn the eyes toward that object, and in using the eyes somewhere else, this tendency has to be resisted. It is not far to see that the neuro-muscular mechanism that has just been described is between two fires, and with the result that a condition of great embarrassment of vision takes place especially in sensitive subjects. It is evident that the light source may be assumed to be provided with a good diffusing envelope, or to be a naked, over-bright filament; in one case it is an invitation for the eyes, in the other it may irritate the retina and cause the reverse tendency in the muscles, that is, a tendency to get the eyes away from it. In either case there is a tendency to disturbance of the equilibrium of the eye muscles. Whether the eyes actually respond and wander away from their work in such a situation is a question which cannot be

answered positively. Undoubtedly the eyes make occasional small excursions away from their actual work under all conditions. With the image of a light source on the retina this tendency is greater, and whether the eyes yield to it or not there is set up a certain nervous strain between two tendencies which may give rise to certain vague, disagreeable feelings known as glare.

Added to this, there may be in some cases a factor of retinal irritation by too high brilliancy. Whereas it was stated above that under practical conditions the intensity of artificial illumination is never absolutely too high as far as the general illumination is concerned, it is a different matter when considering the image of the light source itself on the retina. Leaving flame sources and gas mantles out of the question, it may be said that the incandescent carbon filament at working specific consumption is too bright to have habitually in the field of view. On looking fixedly at such a filament for only a moment, an after-image of the filament will be visible, indicating a disturbance of balance in the retina, which persists for some time. Again, to have a naked filament in the field of view at all, even much to one side, is an irritating circumstance while the eyes are engaged in close work, and the relief found by substituting a frosted lamp, of even higher candle-power is striking.

In regard to diffusing media, one purely mathematical proposition is to be mentioned, namely, the image of any object seen against the face of a lens, prism or other refracting system, is just as bright as the object from which it is formed There is, it is true, always a small loss of light in passing through a layer of glass, but this is nearly constant, about ten per cent. The fact that the image of an incandescent filament seen through a lens appears tenths of an inch in width, while the filament itself is actually thousandths of an inch in diameter, does not mean that the apparent candle-power per square inch, as far as the eye is concerned is reduced a hundred fold. This quantity is reduced in such a case about as much as it would be in viewing the filament through a sheet of clear glass. That is, the eye is looking at a filament a hundred times as large as the actual filament, and (less by an insignificant fraction) exactly as bright in terms of candle-power per apparent square inch. In the case of prismatic reflectors it is only when

they are so far away that the eye is unable to distinguish their individual surfaces, and the media of the eye can themselves perform the necessary diffusion, is there any reduction in intrinsic brilliancy significant for the protection of the eyes. In the case of frosted or sand-blasted glass, the individual refracting surfaces are very minute, the individual images very small, and diffusion is here complete even at close range.

The author is fully aware of practical considerations in the matter of distribution and efficiency which are closely involved in this question and does not mean to pronounce any condemnation of prismatic glassware. There are, however, practical considerations from the eye side of the case. To show how practical the considerations are let a single illustration suffice. A few weeks ago an inquiry was received at the laboratory with which the author is connected as to the state of knowledge concerning the physiological effects of the tungsten light. It seemed that there was an unfavorable opinion abroad as to the effect of tungsten lamps on the eyes, which opinion was found to owe its origin to the expressed opinions of ophthalmologists, presumably derived from their practical experience. Again, the opinion is heard, from medical men, that a good kerosene lamp is the best light-source for eye-work that has yet been devised; that the electric lamp is undoubtedly prejudicial to the eyes, and so on.

Perhaps a consideration of the conditions under which a kerosene lamp is (*or was?*) used may elucidate the question. The lamp is almost invariably set so that the flame is approximately on a level with the eyes of a person sitting in the room. The upper part of the room is darkened by a shade the edge of which is low enough to protect also the eyes of persons sitting in the room. There is therefore not even a kerosene flame visible to the eye, to say nothing of a naked filament. Apart from the question of high intrinsic brilliancy this illustration serves to point out another abuse that the very convenience of incandescent electric lamps has drawn them into. Whereas the mechanical structure and heat of the kerosene lamp compel a respectable distance between lamp and head, an electric lamp when shaded may be put almost between the eyes and the work. Whereas, then, in the case of the kerosene lamp, a reasonable

proportion exists between illumination on the work and general illumination, in the supposed case of the electric lamp the general illumination, when, for reasons of economy all other lamps are put out, is practically zero. Now it has been shown that in the dark, the eye increases in the course of an hour several thousand-fold in sensitiveness, and conversely loses sensitiveness by exposure to strong light. This phenomenon has been found to depend on retinal change (the pupillary change being obviously inadequate to explain it) brought about by the action of light, and is called retinal adaptation. In the case of the extremely brightly illuminated work, in a practically dark room, it is impossible for all parts of the retina to be maintained at all times at anything like the same level of sensitiveness. The part of the retina on which the image of the work falls calls for one level of adaptation, the outlying parts corresponding to the stygian darkness of the room in general call for a much lower level of adaptation, that is, a higher degree of sensitiveness of the retina. Still worse, when direct vision wanders as it does, from the one to the other, the conditions of these different parts of the retina have to be exactly reversed.

Under conditions as described, the "general illumination" must evidently not be confounded with the apparent brightness of the walls, etc., of the room. The apparent brightness of the walls is of course a function of their color (as to lightness or darkness) and the quality of their surface. Comparison of the candle-power per square unit of the walls with candle-power per square unit of the work gives a measure of relative physical brightness of general surroundings and work as these affect the eye, and without pretending to absolute accuracy but simply to call attention to the proposition, one may say that provided there is sufficient illumination on the work to make details comfortably visible the general brightness should not be greater than that of the work. If the general brightness of surroundings is not less than $\frac{1}{x}$ of that of the work, the conditions are favorable. When this is $\frac{1}{x}$ to $\frac{1}{x^2}$, it may be said that conditions are passable. At less than $\frac{1}{x^2}$ conditions are unfavorable.

What it is wished to make clear here is that the brightness of the general surroundings should be somewhat less than that of the work, but not indefinitely less. If asked to state a value for x in the above formulae, the author would say that it is a positive quantity greater than unity, and would add (with the express understanding that it may change without notice) the opinion that it is somewhere near 10.

At the outset it was promised that this paper would come down from the realm of speculation, and land on the solid ground of observed facts. The facts in mind were concerned with the effect on vision at the center of the retina of light in the field of view. The eye at O (Fig. 1) under certain conditions can distinguish letters at A of a certain size (say a). If a light-source be placed at B where the eye can well see it while

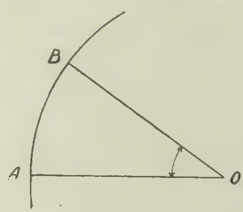

Fig. 1.—Light source in visual field.

looking at A, it is found under certain conditions that the letters have to be *increased* to a size b to become just distinguishable, the illumination on them being the same. The quantity called *visual acuity* has then *decreased* in the ratio $\frac{a}{b}$. This quantity called visual acuity is inversely proportional to the angle at o made by the height of a given test object when it is just visible, and according to the scale in use by ophthalmologists is placed = 1 when the test letters of a standard pattern subtending an angle of 5 minutes at the eye are just legible.

SIDE-ILLUMINATION.

It is proposed here to give a brief history of the question of vision under side-illumination of the eye, and the present state of knowledge of the subject.

Schmidt-Rimpler (1887) investigated the effect on central vision of light on the exposed sclera ("white" of the eye). He

threw a small image of an incandescent filament on the sclera by a lens system (in which case the light source was of course not visible as an object) and found vision for the time being reduced, more so the greater the intensity of the side-light and the less the illumination on the test object. Under opposite conditions (side light of low intensity) he found a reversed condition; there was an increase of visual acuity with the presence of the side-light. He mentions prior observations by Sewall (1884) and Urbantschitch (1883) of this paradoxical increase of visual power taking place in the absence of pupillary contraction where the pupil is stationary under the influence of atropine. Later Uhthoff and Depène, his pupil, (1900) investigated the question very completely for the outer quadrant of the horizon, the side light-source being successively placed at various points on the arc of a circle of which the observed eye was the center, so as to be visible to the eye, as was not the case in the work of Schmidt-Rimpler. They reached similar conclusions with such complete results that it was possible to show graphically just how visual acuity varied with the conditions. Sets of Depène's curves are reproduced in Figs. 2 and 3.

In addition to the facts demonstrated by Schmidt-Rimpler he showed that the depression of vision was greater the less the angle made by the side light-source with the line of vision, and he also found under the opposite conditions,—that is, dim side light-source making a large angle with visual line and high illumination of test object he actually got *increased* visual acuity with presence of the side light-source, which he attributed to pupillary contraction. As to the meaning of this there has been some disagreement. Some hold that contraction of the pupil, making a more distinct picture on the retina is the cause, others say that it occurs as well when the pupil is made immobile by the use of drugs.

More recently Borschke (1904) investigated the question[1] and found that when the image of the side light-source fell on the blind spot of the retina, the effect was in no essential way different from the case where the sensitive retina received the image, showing that a physical factor, scattered light in the eye,

[1] Borschke used the method of determining the increase of illumination on the test-object just necessary to make visible the details suppressed by the incidence of the side-light in the eye.

must have a prominent part in this effect, and not simply the physiological darkening by contrast or by adaptive changes, as the prior observers had concluded. The author confirms this from his own work and adds to it that the reduction of vision is actually greater when the image of the side light-source falls on the blind spot than when it falls on the sensitive retina at the same angle with the visual line.

Heymans (1901) came to the opposite conclusion; that is, that a side light-source whose image falls on the blind spot does not reduce visibility at the center. His method, however, was to use as a visual test the lowest illumination at which a spot of light was visible at all, and found that a second light spot sufficient to suppress this when its image fell on the sensitive retina did not do so when its image fell on the blind spot. As he was working at very low intensities, by a different method his work cannot be held to be contradicting the work of the others named above.

The final items in this history, placed last only because most recent, are the contributions of Messrs. Sweet and Millar. Mr. Sweet especially emphasizes the point that under the conditions of illuminating practice the "glare-effect" does not become noteworthy unless the side-light makes an angle of less than 26° with the line of vision. This result agrees substantially with the results cited here (Figs. 2 and 3) except at the impracticably low illuminations on the test objects and the higher values for the side-light. It is concluded then that there is physiologically no critical angle, that this reduction of vision may be brought about by a side-light at any angle from which light can enter the eye provided the illumination on the test object be reduced or the side-illumination on the eye be increased sufficiently.

One set of conditions which may approach this in practice is the vision of two huge light-sources, each apparently a large fraction of a foot in diameter and of the intrinsic brilliancy of an acetylene flame looming up, presumably from the front of an automobile, out of a relatively dimly lighted field, which is thereby thrown into absolute darkness as far as concerns any objects which may be moving about in it.

But leaving these practical considerations to those who may

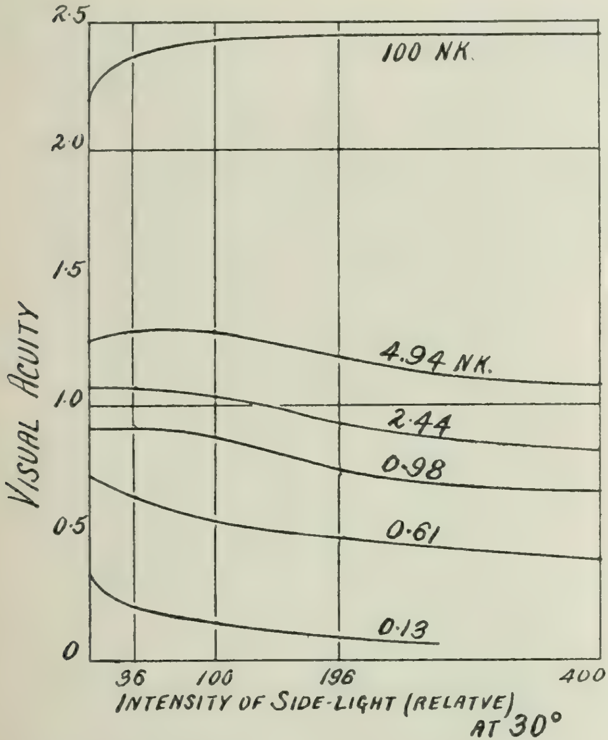

Fig. 2.—Effect of side-light on visual acuity at various illuminations.

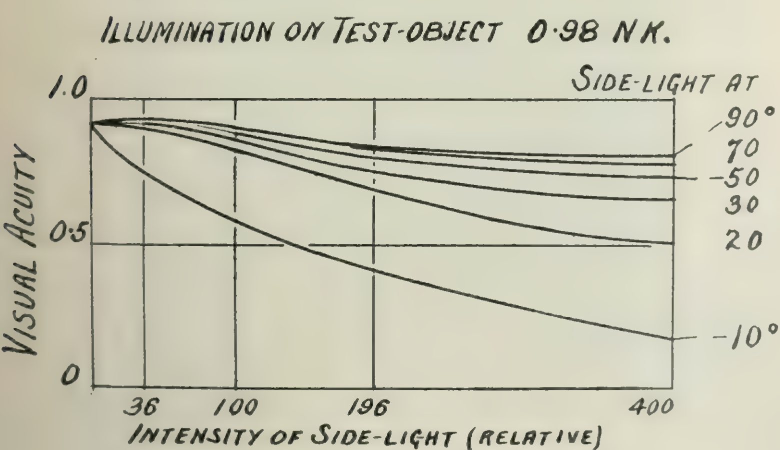

Fig. 3.—Effect of side-light on visual acuity at various angles.

make practical use of them, namely engineers and lawmakers, it is proposed in conclusion to discuss briefly the physiological factors which are concerned in this reduction of vision by light-sources in the field of view.

LIGHT-SOURCES IN THE FIELD OF VIEW.

As was just intimated, those who have worked on the question are divided as to which of two factors is the principal one. These two factors are:

(1) Induction, or change in the adaptive state of the retina, and

(2) The fact of scattered light within the eye from the side light-source acting as a haze thrown over the objects of vision.

It is obvious that the scattered light in the eye can act only while the eye is actually illuminated by the side light-source, and must cease instantly when this is cut off. Further, an effect from this cause must be virtually independent of the intrinsic brilliancy of the light-source, depending only on the total flux of light from it, and will be present when the image of the light falls on the blind spot of the retina.

An actual change in the sensitiveness of the retina may, however, have results which will endure for a sensible period after the eye is shaded from the side-light and might be expected to change with increased area of the light-source, the total flux being the same, since a larger part of the retina is so stimulated. Further, the effect would be nil in so far as the image of the light-source fell on the blind spot of the retina.

The facts on these points are:

(1) That the reduction of visual acuity is greater when the image of the side light-source falls on the blind spot of the retina than when it falls on a light-sensitive spot equally distant from the center. This speaks for the dependence of this phenomenon on scattered light in the eye.

(2) With the same light-flux on the eye, a sand-blasted glass before the side light-source caused a small and uniformly greater depression of vision than the visible filament with clear glass, quite contrary to the expected result, for all angles of incidence including 50 degrees. This means that increased area of retina stimulated disturbs central vision more, and speaks unmistakably for a distinct change in the sensibility of the retina.

(3) As far as the experiments have gone, the visible filament caused a residual persistence of the depression of vision which could be shown to endure about half an hour (after 15 minutes work of the eye under the glare) and which the diffused source failed to bring about.

It is concluded then that scattered light in the eye from a side light-source is a large factor in reducing visual acuity, and that there are, further, probably two effects relative to the sensitiveness of the retina itself, one called forth by the extent of retinal surface stimulated by the side-light, and transient; the other the result of high intrinsic brilliancy of the side light-source and persistent (to a degree) after the side-light has ceased to act for a fraction of an hour.

A man who devotes his time to research without direct practical application is often under suspicion of wasting his time in making hair-splitting distinctions, with no object but the satisfaction of his own personal curiosity. In the present case it seems near to point out a fact that hinges on this very distinction. Obscuration of vision by scattered light in the eye *per se* need be no more harmful to the eyes than looking out of a window into a fog. If, however, one can distinguish a definite change in the retinal state under side-illumination of the eye which may persist after the light is cut off, the possibility is not far to a practical application of this distinction. Although under practical conditions the actual reduction of visual acuity by this feature of glare is not so great as to cause in itself serious embarrassment of vision, yet it can be looked upon as a symptom by means of which the physiological diagnosis of a system of illumination may possibly be made in a scientific way, instead of the method of trying it out under actual conditions, so wasteful of time, capital and human eyesight.

ARTIFICIAL ILLUMINATION AS A FACTOR IN THE PRODUCTION OF OCULAR DISCOMFORT.[1]

BY NELSON MILES BLACK, M. D.

It is a generally conceded fact that improper use of modern artificial illumination is a source of ocular discomfort, and to an extent that individuals whose vocations require its use are often seriously handicapped.

Long before the days of artificial illumination it was know that injury of the eyes was a frequent result of exposure to excessive light. Eclipse blindness was known to the ancient Greeks. Snow blindness is frequently referred to in the writings of the earliest artic explorers, and transient blindness and cataract are not infrequent results of exposure to lightning flashes, while electric ophthalmia since the advent of electricity commercially is of rather common occurrence.

SYMPTOMS OF OCULAR DISCOMFORT.

In the above mentioned conditions the clinical picture is such that the injurious action of bright light is unmistakable. The discomfort complained of by workers under artificial illumination is of an entirely different character. One individual may be affected differently from another. The most common complaint after a longer or shorter period of exposure is that the eyes feel dry and hot with a sense of fullness about them and the details of objects looked at become a little blurred as if the illumination were being diminished. At this stage winking is noticeably increased. Next the finer details of objects are practically lost for an instant and can only be brought out by closing the eyes for a few seconds; there is in some instances an actual ache in the eyes and head, mental activity is dulled, there is almost a complete inability to keep the eyes open, together with marked drowsiness. The eyeballs and lids show more or less congestion. A short rest with the eyes closed frequently brings about a marked sense of relief which upon resuming the occupation gives place to the same train of symptoms that now make themselves manifest much more quickly. Increasing the in-

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, January 12, 1911.

tensity of the illumination will for a short time tend to give apparent relief but this is quickly followed by greater discomfort. Continued use of the eyes under these conditions becomes absolutely painful and not infrequently impossible. Correction of refractive errors by properly fitted lenses does in some measure give relief, but this is undoubtedly because they relieve the eye of some strain. However, permanent relief is obtained only by change of occupation. Rest will bring about temporary relief, the symptoms returning when the work is again undertaken. No permanent pathological changes take place in the eye.

In all honesty it must be confessed that ophthalmologists are woefully ignorant as to the exact cause of this ocular distress, one reason being that the changes which take place in the visual apparatus when subjected to bright light are not well understood and still less is known of the changes which take place when the eye is subjected to the spectra of different illuminating sources. As a result no adequate means of relief have been suggested.

VISUAL APPARATUS.

In order that the results obtained by various investigators may be fully understood it is thought best to give a brief description of the different parts of the visual apparatus, although, probably all illuminating engineers are familiar with them.

In order to produce a visual impression a ray of light must pass through several transparent media each of which has the power of absorbing a portion of the rays it transmits. In their respective order these are: (1) the cornea; (2) the aqueous humor; (3) the crystalline lens, and (4) the vitreous body.

The ray of light finally impinges upon a complex nervous mechanism, the retina, which is the innermost tunic and perceptive structure of the eye, formed by the expansion of the optic nerve. This tunic consists of ten layers: of these only the two outer layers particularly interest us. These are the layer of rods and cones, and the pigmentary layer. "The layer of rods and cones forms the percipient element of the retina, in the center of the posterior part of which is the malcula lutea, the most sensitive portion of the retina, and in the center of the malcula lutea is a depression, the fovea centralis, the point of

sharpest vision. In the fovea only cones are to be found. Immediately external to this area each cone is surrounded by a ring of rods. The number of rods around each cone increases as the periphery is reached. The outer segments of the cones are situated in a space which is filled with fluid and an external lining membrane retains this fluid in place."

The cones are *supposed* to be the form-receiving and color-perceiving elements of the retina; in other words, they are the visual cells.

The supposition is that the rods are the special apparatus for vision in dim lights (night vision). They contain a pigment known as rhodopsin or visual purple, which is very sensitive to light. This visual purple is found only in the external segments of the rods; the cones do not contain it; therefore the fovea, which has only cones, does not contain it. It has been shown that a photograph may be made upon the surface of the retina by the bleaching of the visual purple where it is exposed to light. In the visual purple, there is therefore, an unstable substance readily decomposed by the mechanical or chemical effect of the ether waves. Some radiations are very much more active than others in bleaching this substance, greenish yellow being most active, yellow next, blue next, violet next and red least active in this process. It has been shown that provision exists in the retina for the constant regeneration of the visual purple. The restoration process takes place rapidly in dim light or darkness. The external segments of the rods impinge upon a layer of heavily-pigmented cells—the pigmentary layer mentioned above. When the eye is exposed to light the black pigment of these cells migrates so as to be in position to restore the color to the bleached or used up visual purple. All of this explanation may seem unnecessary but must be kept in mind in order that the latter part of the paper may be understood.

EFFECT OF BRIGHT LIGHT.

The range of intensity of illumination to which the eye can adapt itself is enormous. Compare, for instance, the feeble intensity by which one is able to read, less than one foot-candle, and the brilliant illumination of the midday sun. The length of time the eye may be used with comfort, however, is manifestly

greater with the weaker illumination. A retina protected from light for a time will distinguish an intensity of illumination absolutely invisible under other conditions. This adaptation of the eye is due to the restoration of the photochemic quality of the visual purple which is used up as the result of exposure to light.

We all know the discomfort produced by the reflection of bright sunlight from a body of water, a wet road, the surface of a white building, or snow, with the sun somewhere in the line of vision; and in speaking of this effect it is referred to as "glare." In order to produce glare, the sun need not necessarily be in the line of vision, it may be behind the back or overhead especially in deserts where the atmosphere is clear and the ground surfaces generally white. If, however, as in the tropics, the ground surface is green from vegetation, glare is conspicuously absent. The intensely bright beams from a calcium lamp, the acetylene lamps of an automobile, the flash from a light-house, or the electric head-lamp of a locomotive, or any bright lamps in the line of vision are sources of glare with which all are familiar.

A marked form of glare is experienced in passing from a dark room into a brilliantly lighted one, or into the bright sunshine; in this case some little time elapses before the visual apparatus so adjusts itself that objects are distinguished clearly.

ULTRA-VIOLET LIGHT.

It has been clearly demonstrated that exposure of the unprotected eyes to light having a spectrum including wave lengths extending far into the ultra-violet produces very serious and often lasting injuries. These, however, are so marked that their identity is unmistakable and differ markedly from the ocular discomfort under discussion. The result has been that the violet and ultra-violet rays have been considered the cause of all the eye trouble extant and nearly all investigations of the subject have followed these lines.

The visual spectrum as is well known "includes raditions having wave lengths of about 723 microns at the red end to those of about 397 microns at the violet end. Beyond the red end are rays of greater wave length which cause a rise in temperature. Beyond the violet end are rays of smaller wave length which are

capable of causing chemical reaction. These latter rays are spoken of as the ultra-red and ultra-violet rays respectively and, while the ultra-violet radiations are particularly potent in inducing chemical action, the visible rays are also actinic though in less degree, and the same is true of the infra-red in still less degree."

The actinicity of the various wave lengths of the spectrum may be strikingly demonstrated with a specially-sensitized photographic film by passing the rays of light through a train of lenses and prisms made of quartz which allow the maximum number of rays to pass unimpeded.

ABSORPTION OF ULTRA-VIOLET RAYS BY OCULAR MEDIA.

By interposing the refractive media of the eye, that is, the cornea, lens and vitreous body, in a ray passing through a train of lenses and prisms the absorptive power of each may be shown upon the photographic plate.

"The following are the results obtained by Mr. Herbert Parsons of London: The eyes of young rabbits were used in each instance. "All the media were found to be uniformly permeable to rays between the wave lengths 660 to 390 microns. (The visible spectrum extended from approximately 760 to 380 microns.)

"For the ultra-violet rays the iron arc was the source and quartz was used throughout. Ordinary plates were used, that is, plates containing no dye and hence giving no absorption bands. The range of wave lengths covered in this series was from 450 to 230 microns.

"*Cornea.* The cornea was found to offer no resistance to rays of wave lengths longer than 295 microns, but all of those beyond this limit were completely cut off.

"*Lens.* (a) Suspended in normal saline. Rays of wave lengths less than 350 microns are absorbed completely. The line is not a sharp one, the absorption commencing at about 400 microns. (b) Squeezed to different thickness. The absorption varies *pari passu* with the thickness of the layer of lens substance.

"*Vitreous.* The vitreous in a layer 3/16 inch thick shows a broad absorption and extending from 280 to 250 microns, with

a maximum at 270 microns. The margins of the band are ill-defined.

"These results agree closely with those recently obtained by Schanz and Stockhausen and Birch-Hirshfeld."

Thus it will be seen that with the cornea absorbing rays of wave lengths less than 295 microns and the lens those less than 400 microns, practically no ultra-violet rays reach the retina so that their ill effects upon the eye, if any, would probably be entirely superficial and to produce symptoms similar to mild electric ophthalmia, that is, pain, photophobia, lacrymation, hyperaemia, swelling of the conjunctiva and mucoid discharge, which are not the symptoms under discussion.

ABSORPTION OF ULTRA-VIOLET RAYS BY ILLUMINANT ENVELOPES.

There is an additional eliminative factor, as far as ultra-violet rays are concerned in connection with the source of illumination itself. To quote Dr. Steinmetz, "While artificial illuminants, and especially metal arcs, give an appreciable amount of the ultra-violet light, these ultra-violet rays extend only to about one-quarter octave beyond the visible violet. If, as is always the case, the illuminant is enclosed by glass, the harmful effect of these long ultra-violet rays is negligible: the radiation of the sun also contains ultra-violet rays and a larger percentage compared with the total radiations than any glass-enclosed artificial illuminant, and as the light of the sun, that is, daylight, is recognized as perfectly harmless, as far as this specific destructive action is concerned, the same applies to the artificial illuminants, as they contain less ultra-violet rays than the light of the sun." The harmful effects of ultra-violet to the superficial portion of the eye are apparently thus eliminated.

LUMINOUS RADIATIONS.

If such is the case the harmful effects must come from luminous radiations of greater than 400 microns wave length. The experiment of Best would seem to prove this. "He found that he could safely look for ten seconds directly at the midday sun in the summer through blue uvial glass, which cut off a large proportion of the luminous rays but transmitted all rays of wave length between 405 microns and 332 microns and a considerable

part of those of shorter wave length. After the exposure he saw a yellow after-image of the sun for a few minutes, but this was not sufficient to prevent him reading. On the other hand he found it impossible to 'fix' the sun even for the fraction of a second, when looking through yellow glass which cut off all ultra-violet rays."

Comparable with the Best experiment is the distress manifested by albinos under conditions of illumination in which the average normal individual is perfectly comfortable. These individuals have white or very light-colored hair, their irides and inner coats of the eye are pink, owing to the lack of pigment. The pigment cells are present but contain no pigment. It is impossible for an albino to "fix" any object as the eyes are constantly in motion, a condition known as nystagmus. This is probably nature's method of preventing to as great an extent as possible, retinal irritation, as no one point of the retina is subjected to the unprotected effects of light for any length of time. Smoke or tinted glasses, which reduce the intensity of the luminous rays which reach the retina do much toward alleviating their distress.

In this connection it may be mentioned an inverse comparison, the night blindness produced by exposure to bright lights. Quoting Mr. J. Hilbert Parsons, "Prolonged exposure to bright lights in the tropics and at sea is not infrequently followed by night blindness. These cases are of peculiar interest, since they show in a marked degree the effects of retinal exhaustion. It was shown long ago that if one eye is bandaged and thus protected from light during the day the night blindness is warded off as far as that eye is concerned. It is almost certain that the retinal exhaustion in these cases is due primarily to bleaching of the visual purple, which is not restored with the usual rapidity. In some cases of this kind malnutrition plays a part but others occur without this factor. Night blindness has been known to follow a long motor drive facing the sun which was near the horizon and consequently shining directly into the driver's eyes.

"Now these changes in the retinal purple are chemical in character and might be expected to be induced most readily by the most actinic rays of the spectrum, namely, the ultra-violet

rays. These are known to be responsible for so-called "snow blindness," but this is a superficial inflammation of the mucuous membrane covering the eye and is of a completely different character."

The question then is why are workers under artificial light prone to ocular discomfort.

The author has an hypothesis to advance based upon three primary factors, namely, (a) the theory of vision as advanced by F. W. Eldridge-Green; (b) the effect of light from various illuminating sources upon the visual purple of the retina; (c) the question of evolution.

There are two or three other important factors which will also be mentioned.

(a) Eldridge-Green in his theory of vision assumes, "that the cones of the retina are insensitive to light, but sensitive to chemical changes in the visual purple. Light falling upon the retina liberates the visual purple from the rods and it is diffused into the fovea and other parts of the rod and cone layer of the retina. The decomposition of the visual purple by light chemically stimulates the ends of the cones (probably through the electricity which is produced) and a visual impulse is set up, which is conveyed through the optic nerve fibers to the brain." He also assumes that the visual impulses caused by the different rays of light differ in character just as the rays of light differ in wave length. Then in the impulse itself there is the physiological basis of the sensation of light, and in the quality of the impulse the physiological basis of the sensation of color.

He has assumed that the quality of the impulse is perceived by a special perceptive center in the brain with the power of perceiving differences possessed by that center or portions of that center. According to this view the rods are not concerned with transmitting visual impulses, but only with the visual purple and its diffusion.

In support of the assumption that the cones of the retina are insensitive to light Eldridge-Green says, "If the cones are not sensitive to light, a ray of light falling upon the fovea alone and not upon the adjacent portion of the retina containing rods should produce no sensation of light, provided that there is not already any visual purple in the fovea.

"It has been known to astronomers for a long time that if a small star in a dark portion of the sky be looked at steadfastly it will disappear from view, whilst other stars seen by indirect vision remain conspicuously visible. The following simple experiment shows the same thing. If a pin be put in the center of a piece of black velvet three feet square on a door and the source of light be behind the observer, the pin will be brightly illuminated, and on looking at it (the observer not being too close) and keeping the eye quite still the pin will disappear, the visual substance diffused into the fovea centralis being used up and not renewed. When viewed by indirect vision it is impossible to make it disappear in this way. When I have taken great care to have very dark surroundings and have used only one eye I have made moderately bright lights disappear in this manner. The greatest difficulty is found with red light, which is very difficult to make disappear. This, however, one should expect from the knowledge of the visual purple, for red light bleaches it very slowly, and therefore a much longer time would be required before the visual purple already in the fovea was used up."

Kühne, who has done so much in connection with photochemistry of the retina and visual purple expresses an opinion "that the visual purple could not be essential to vision because it was not present in the cones," but as Eldridge-Green remarks, "he does not appear to have looked for it between the cones" and it seems to him "more probably that the rods should produce a secretation which would affect cells other than themselves."

Eldridge-Green has demonstrated visual purple between the cones microscopically in the eyes of monkeys.

Assuming that the above is the true theory of vision, an absolutely essential factor to the visual act is an unstable photo-chemical substance, generated in the rods of the retina, which is decomposed by the action of light. This decomposition taking place most rapidly in the presence of light at about the middle of the visible spectrum: that is, greenish yellow or yellow radiations have the greatest bleaching effect. Absence of light is necessary for its reproduction or restoration.

(b) In comparing the spectra of artificial illuminants with the spectrum of sunlight a marked difference is found. Practically all sources of commercial illumination are deficient in blue

rays as compared with sunlight. Blue is the complimentary color of yellow and neutralizes it. Artificial light lacking blue to neutralize its yellow has then a greater proportion of yellow rays which are next active to the greenish yellow in bleaching the visual purple.

(c) Evolutionary changes in an organ of the body are the result of a change in the environment extended over very long periods of time. Since the advent of man upon the earth the light of the sun, moon and stars has been practically the only source of illumination. The torch of ancient times and the rush light, candle, whale oil lamps, and various forms of oil lamps of medieval and early modern days were not extensively enough used and not of sufficient intensity to have been a very great factor in the evolution of the eye although they probably exerted some influence.

The real cause for an evolutionary change to take place was brought about with the discovery of the refining process which produced an efficient artificial illuminant from petroleum about the year 1854. This was practically the beginning of real commercial artificial light. Edison produced the carbon incandescent lamp in 1878, since which time the number of hours the eyes are used for close work under artificial illumination have been enormously increased. Improvements have been inaugurated almost daily and always with a view of increasing the efficiency of the illumination which usually ends in increasing the intensity with no thought as to the physiologic effect upon the eyes.

It must be apparent that far from sufficient time has elapsed for evolutionary changes even to begin to adapt the eye to the comparatively abrupt change in environment.

The hypothesis submitted then is that at least a part of the ocular discomfort observed from use of the eyes under artificial light results from the irritating effect of the luminous or visible radiations of such illumination upon the unprotected retinal elements. The visual purple which is an essential factor to vision and is the protective agent to the retinal elements against light, is used up by improper use of illuminants, having spectra with relatively more radiations which decompose this photochemic substance more rapidly than sunlight. This irritating effect is probably greater because insufficient time has elapsed for evolu-

tionary changes to adapt the eye to modern artificial illumination.

It must be confessed that the present state of our knowledge is insufficient to formulate a satisfactory theory as to the actual cause of ocular discomfort from artificial illumination. The above hypothesis has been advanced as a possible basis for further specific experimental investigation and an appeal is made to the members of the Illuminating Engineering Society for aid in carrying on such an investigation.

Other factors which tend to promote discomfort are the result of exposure of the eyes to bright light, either direct, reflected, diffused or diffracted, which produce reflex action of the lids and iris. The lids are screwed up, the brow puckered and the iris maintained in a state of constant contraction in order to exclude the light. The expenditure of nervous energy required to bring this protective mechanism into play tends to produce brain tire and drowsiness, while the fatigue induced by the constant muscular contraction makes itself manifest as discomfort in and about the eye. This is especially marked when bright light is reflected upwards into the eye as undoubtedly all have noticed when reading print upon paper having a high glaze. The same result is equally marked after a short time in a room brilliantly lighted artificially.

The question naturally comes up: why is the effect not as marked when the eyes are exposed to the brilliant sunlight of a clear day? There are several factors:

(1) There is only one source of light and one can usually prevent the rays from striking directly in the eye.

(2) The light is diffracted and diffused by its passage through the ether, especially so on days when there are clouds in the sky.

(3) There is as a rule a constant change in the intensity of the light except upon deserts or prairies. This is a very great factor in the production of ocular comfort.

(4) The eye has innumerable chances for rest and change in the countless marked shadows of different intensity found in brilliant sunlight, except in deserts and prairie countries, which latter do not produce as much ocular discomfort as a brilliantly lighted auditorium.

(5) The color schemes in nature are a prime factor in ocular comfort.

Do any of the above conditions obtain in the average illumination installation? In artificial lighting the sources of illumination are innumerable and, as a rule, many units are included within the field of vision, so that the intrinsic brilliancy of each point of light while not striking directly upon the fovea itself, impinges upon other portions of the retina in the immediate neighborhood. This uses up the visual purple needlessly which should be diffused through the macula where it is required to produce visual impulses. In addition the automatic protectors of the eye, the lids and iris, are forced into action.

The source, which is amply sufficient for the purpose intended, is frequently shaded within a reflector which directs the rays upon the object "fixed," from which they are reflected directly into the eyes, the original intensity of the unit being increased by the reflector to a point far beyond actual requirement. If diffusing or diffracting envelopes are used, the intrinsic brilliancy of the unit is reduced in intensity but is still within the visual field and continues a factor in causing discomfort.

In artificial illumination there is no change in the intensity of the light such as is met with in daylight, during which the eye may have a chance for relaxation and restoration of the photochemical substance. The shadows produced may or may not be considerable and are usually in a position where it is almost impossible for the eyes to "fix" them in order to allow relaxation. The color schemes in indoor decoration are, as a rule, all worked out under daylight, very little thought being given to the effect produced by artificial illumination or the physiologic effect upon the eyes.

Ocular comfort in close use of the eyes under artificial illumination may, to a certain extent, be secured by using protective media, such as lenses having the power of absorbing certain radiations or of diminishing the intensity of the rays; in some occupations this is absolutely essential. In all probability, however, the most important factor is to determine exactly what physiologic effect artificial light has upon the eyes, and let such findings be a guide as to its proper use. The problem is no easy one but its solution is very essential to the ocular comfort of coming generations, which should be sufficient stimulus for immediate and earnest investigation by all the departments of science involved.

DISCUSSION OF COBB AND BLACK PAPERS BY THE NEW YORK SECTION.

Dr. John E. Weeks:—The subject of illumination is one that is well worthy the careful consideration of engineers,—a subject which should be studied not only from the standpoint of physics, but also from the standpoint of physiology. The subject is such a broad one, and is of such importance, that the present beginning should certainly be pursued until satisfactory conclusions have been reached from scientific data.

In regard to the annoyance from bright light, many questions are involved. It is a fact that in man and in certain other animals visual purple exists. It is also a fact, (or at least those who have studied the matter so state), that in certain animals with good vision visual purple is not present. It is conceded that the portion of the spectrum mentioned by Dr. Black, as not exactly a perfect yellow, apparently reduces the visual purply more actively than any other portion of the spectrum, and a marked absence of light of this nature is necessary to permit reproduction of the visual purple.

The study in regard to the cells which produced the visual purple is not as yet complete, although it is believed generally that the rods are the portions of the retina that are so concerned. The rapidity of the reduction of the visual purple depends largely on the intensity as well as on the color and also the volume of light that enters the eye. This is regulated by a curtain spread before the lens known as the iris, which required an appreciable time to contract and dilate—adapt—itself to the varying conditions. The exhaustion of the visual purple when one passes from a dark room into light, is rapid because of the lack of time for adaptation of the iris, or, in other words for lack of time for proper contraction of the pupil. There is also a retinal and a pigmental "adaptation" but the main cause is the size of the pupil.

The quality and the intensity of the light, in addition to the proper adaptation of the pupil, are factors in determining the *ease* of vision. At the present time it is very well known, or very well settled, about how much light is required on an illuminated surface to give ease in vision. It is known that day-

light is best adapted for the eyes. The quality of the artificial illumination is not fully decided. That is a large field for study. However, in any event, the source of light should be above, generally speaking.

The question as to illumination by side light sources is one that is of much importance, and one that affects very vitally the lighting of audience chambers whether they are lighted by artificial or by natural illumination. The nearer the source of light approaches to the visual line, the more is the eye confused. When an audience chamber is illuminated, the source of light should be removed at least 25 degrees from the visual line. This fault in illumination is frequently observed. One of the worst lighted rooms in the State of New York is the Senate Chamber, at Albany, in which side sources of illumination are numerous, many within ten, fifteen, twenty or twenty-five degrees of the visual line. The President of the Senate sits behind a circular table which is surrounded by a number of incandescent lamps. Below him is another semi-circular table, the Clerk's desk, on which there is a number of lamps which are not protected in any way, and above his head are lamps with naked filaments. The glare that the Senators experience in trying to see the President is quite enormous. The reason for this is in large part because the contraction of the pupil occasioned by the intense side light units is such that the illumination coming from the object looked at, namely, the President of the Senate, does not afford sufficient rays of light to produce a proper image on the retina; the constant warfare between the desire to obtain rays of light from the object looked at, and the desire to shut out the excessive amount of light from the light sources, produce great eye fatigue in the individual so engaged.

Dr. H. H. Seabrook:—In criticising a paper which is so generally excellent as that of Dr. Black, I wish it understood that there are only these few points in opposition I wish to make.

About three years ago I read a paper before the Society in which I called attention to the injuries done to the eyes by illumination in general. I took up artificial illumination, and when some doubt was expressed by those interested in artificial illumination regarding these injuries, an argument I used was

to produce a paper which Dr. Black had written as to injuries to the eye from light.

In the first place direct injury from the sun is not proven to be due to ultra-violet rays. Birch-Hirschfeld, in 1904, called attention to the fact that spectral light does not injure the eye, but only ultra-violet; but in reading the text in the language in which it was published, I found that while one experimenter had shown this to be the case others had shown that chemical rays of the spectrum injure the eye. There is confusion due to the fact that some when referring to light, refer to all of the spectrum, others to the light rays only; and when speaking of chemical rays sometimes only ultra-violet rays are intended while at other times all chemical rays are included.

The question of visual purple has been under discussion as to its importance, but there is no doubt as to the importance of the migration and breaking up of the pigment cells of the retina by light. The pigment cells being broken up, shows retinal exhaustion.

Along about 1884, Van Gendesen Short showed that the migration of pigment cells is at a minimum in yellow light. In 1904, Arnold Staerkle took up the question, and employed a glass which was the old smoke-glass with yellow. This has been used as a protective glass in Germany, with great success, and is called Fieuzel glass, from its original proposer, its only fault for general use being a virtue in pathological cases as it cuts off about 50 per cent. of the illumination as well as chemical rays.

I am decidedly of the opinion that the chemical rays of light are the ones that cause most damage, and experiments on animals have shown the production of cataract by their use; and the fact that cataract is prevalent in India and on the planes of Mexico seem to bear that statement out. Tyndall showed that the chemical, including ultra-violet rays, are absorbed by the atmosphere; hence snow blindness occurs only in high altitudes; while in the valleys it is not prevalent. Amber yellow glass is used with better effect than Fieuzel.

As regards the question of glare, I have defined glare as an excess of light which causes discomfort to the human retinas. Hence what would be glare for one person would not be glare

for another. Illuminating engineers can only treat the subject on general principles, and trust to the oculist to do the rest.

Illuminating engineers who have been solving these problems for the last few years, have decided that the artificial illumination for one purpose will not do for all others, and that the general illumination of the flaming arc and other strong lamps, while each is good for its particular purpose, would not be proper for reading.

There are a few points of practical interest to illuminating engineers and others in order to avoid damage to eyes from excess of illumination. First, the intensity of the image in the incandescent lamp because of the small filament causes greater damage to the eye than if the light were diffused. It has been shown that the eyes are constantly shifting about; they are never steady for any length of time, but are always moving so that light is not focused with intensity on any one spot on the retina.

Next the two questions of distance and position are subjects of extreme importance to our specialists and illuminating engineers. The position of the light source in front makes the reader bend over, whereas from the rear it makes him sit up. If it is in front, it makes him bend over and it congests the muscles of the neck and chest, and it is supposed in Germany to produce near-sightedness.

In what little work I have done in the last few years, I have found that most people with eye discomfort due to light will be benefitted by attention to these simple points.

Dr. Black:—In regard to the statement that ultra-violet light is a factor in the production of eye damage, in my paper there is nothing contradicting this statement. Ultra-violet rays are productive of a great deal of damage to the eye, and they are also a factor in the production of cataracts. In India and Mexico the reflection of the sunlight from the broad stretches of desert and from the snow in Labrador, results in a glare that is intense. As Parsons states, it is his observation that "the changes in the retinal purple are chemical in character, and might be expected to be induced most readily by the actinic rays of the spectrum—namely, the ultra-violet rays. These are known to be responsible for the so-called "snow-blindness," but this is a

superficial inflammation of the mucous membrane covering the eye, and is of a completely different character from the ocular discomfort under discussion.

The cause of the intense pain in the eye is the extreme congestion, which extends deeply into the orbit. The nerves from the orbit go through a small foramena or opening in the bones of the skull and these cause pressure upon the congested tissue and produce that pain.

As to the cataracts, in India, Mexico and Labrador, the natives are frequently subjects of malnutrition as the result of famine,—notably so in India. As a consequence the nourishment of the lens is reduced, the lenses of some individuals are more subject to these changes, and it is this character of lens which undergoes the change. These changes occur also in individuals working in intense heat, such as glass blowers. In those men whose systems are run down and their nutrition reduced, cataracts are found. The Esquimaux have at all times one or other extreme,—either a feast or a famine.

Dr. Seabrook spoke of the yellow glass used by Alpine tourists. That is used to protect them against the ultra-violet rays. The reflection from the snow is very great and the glare intense at those altitudes. It is true that ultra-violet rays are the cause of a great deal of damage to the eyes; but my paper says distinctly that it is ocular discomfort due to artificial light in which there are no pathological changes in the eye.

Mr. S. W. Ashe:—The subject of glare is one which from time to time has caused considerable discussion. Various theories have been advanced and a new and interesting theory, namely, that of muscular ocular discomfort is introduced in the paper by Dr. Cobb. In considering this subject, I have always been partial to the theory that glare is caused by scattered light in the eye which necessitates high intensity to obtain the same sharpness on the retina.

In this respect, the eye may be likened to a camera where one is attempting to photograph an object with the sun in the field of the camera. In taking such a photograph a fogged plate is obtained; objects, unless they are highly illuminated, are indistinct. The eye probably acts somewhat similar to the

camera in this respect, where glare exists. It is necessary to raise the intensity in order to produce the same acuity.

In comparing illuminants, in the future, acuity will doubtless play a more important part than in the past. In comparing two illuminants—A and B—it may be found that in their ability to produce the same illumination, A will be cheaper than B, but when a comparison is made on an acuity basis, B may be cheaper than A. The difficulties in making comparison on an acuity basis is that the color of the illuminant plays a very important part. B may be cheaper than A when acuity is determined with a black object upon a white background, but where the color of the background is other than white, the conditions may be reversed.

Mr. H. T. Owens:—Dr. Cobb states that the minimum discomfort would be obtained with the maximum light in the lower part of the room. However, it is usually considered that better results are obtained when the major illumination is in the upper part of the room, and not down in the lower, and it is very unusual to have the source of illumination in the lower part of the room. It is held by some persons that the proper way to illuminate a room is to place a reflector below the lamp and direct all of the light upward against the ceiling.

Dr. Black:—All objects are seen by reflected light, unless they are self-luminous; and, if the sources of illumination are in the lower part of the room, they will be in the field of vision where they will be a source of discomfort as the result of their intrinsic brilliancy.

The source of light should be high, and the light should be rightly diffused, reflected and refracted and diffracted before it gets to the bottom of the room, with the main flux of illumination directed upon the objects which are to be observed.

Dr. Cobb states that in general illumination, it is best to keep the eye in a perfect state of adaptation. I think that is absolutely wrong. One must have a change in the intensity of illumination, so that the eye may become rested; so that the visual purple may be restored, and active vision go on.

If in general illumination there are no shadows to relieve the monotony and to allow the visual purple to be restored, there will be a gradual decrease in visual acuity; when a side

light source is within an angle of, say, 26 degrees, rays of light other than those from the object fixed enter the eye, and use up the visual purple with the consequent loss of visual acuity. When the eye is moved out of that angle, the visual purple is not affected so much. The eye is also protected by the iris, the lid, and brow.

When there are two sources of illumination, one in which the intrinsic brilliancy is from a naked filament, and the other is diffused like a globe, the visual acuity is not changed. But the greater discomfort noticed under the bare filament, is due to certain areas of the retina having the visual purple used up from the brilliant light of the filament, and such areas are subjected to great irritation as the visual purple cannot be supplied rapidly enough to protect them.

As to the loss of vision owing to a side light being within a certain angle on either side of the line of vision, it is well to mention certain tests made by Dr. Chamberlain, consulting oculist of the Great Northern Railway, who investigated the engine men's ability to distinguish signals under similar conditions. At one end of a long room several signal lamps were so arranged that the various colors could be placed before them; in front of the men was an electric "headlight," directed toward the signal lamps.

The men were in the relative position of an engineer in a cab with the "head-light" directed on the track in front of them. So long as the light was thrown on the signal lamps with the angle of incidence such that the reflected light was not in the line of vision, the signal could be distinguished. Then an electric headlight was switched on for fifteen or twenty seconds as of the headlight of an engine coming around a curve. Out of the seven men on trial, not one distinguished all of the colors properly, under these conditions. Some would call the red brown, and some would call it yellow, but in no instance did any man determine all of the colors, simply because the visual purple had been used up by the glare from the light in the line of vision.

Dr. Cobb:—My investigations have shown the existence of a marked difference between ocular discomfort and depression of the visual function. The question of glare should not be confined to any one of these points alone, because all of the many

factors should be considered. Glare begins at the retina, but disturbance of the eye muscles does play a part and must be considered in this connection.

Concerning adaptation, I do not hold that an absolutely uniformly illuminated field of view is good for eye comfort. Contrast is needed to give rest to various parts of the retina, but contrasts can easily be carried to an extreme. The point I wished to make in my paper is that the general illumination of a room should be somewhat proportioned to the illumination of the work.

That discomfort and visual depression are different phenomena has been shown by some tests which, contrary to my expectation, indicated that sources of higher intrinsic brilliancy in the visual field produced a larger degree of discomfort with no more disturbance of the actual power of the eye to see detail than the same intensity of light on the eye coming from a diffusing screen.

THE LIGHTING OF A LARGE STORE.[1]

BY CLARENCE L. LAW AND ALBERT JACKSON MARSHALL.

In the fall of 1910, Gimbel Brothers' large New York store, occupying the block between Thirty-second and Thirty-third streets, facing Broadway and Sixth Avenue, was opened to the public. There are ten stories above and three below the surface of the ground; the McAdoo Tunnels, to lower New York and under the Hudson to several stations in New Jersey connecting with one of the basements. The building was designed by D. H.

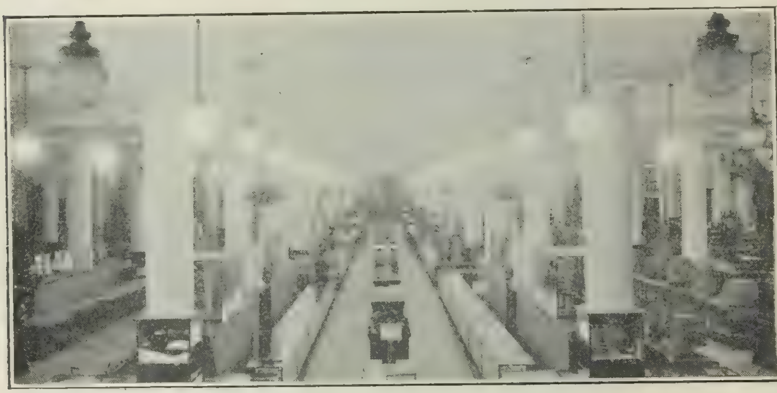

Fig. 1.—Main aisle looking east towards Sixth avenue.

Burnham Company, architects, of Chicago, and built by the Thompson-Starrett Construction Company of New York. Some idea may be obtained of the magnitude of this building from the following statistics furnished by the architects and builders: It has 120 flights of stairs, which if made into one continuous flight, would extend upward 1,680 feet—more than twice the height of the largest building in the world. Over 100,000 square feet of plate glass is used on the outside of the building alone. This would cover a surface larger than three average city blocks. There are 2,406 steel columns in the building, having a combined height of over 6 miles. The rock excavated for the space oc-

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, March 9, 1911.

cupied by the sub-basement, basement and basement mezzanine

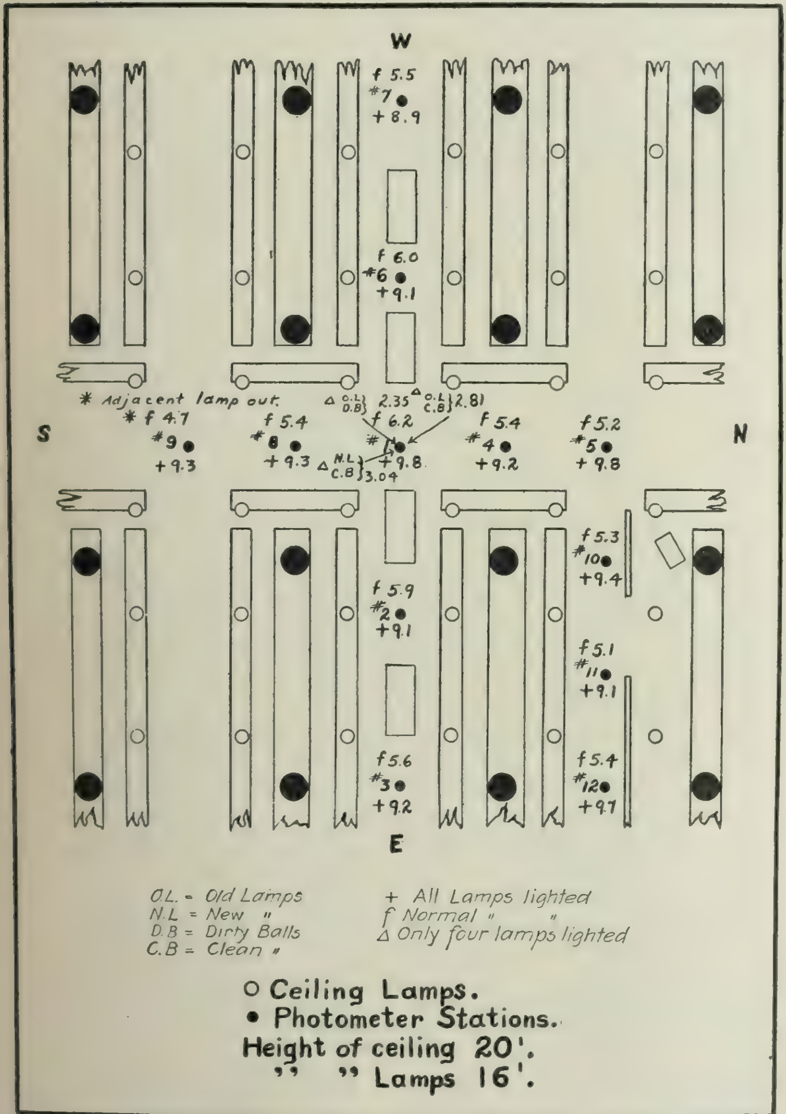

Fig. 2.—Section plan of main floor, showing location of furniture, pillars, lighting units, test stations and illumination data.

totalled 2,970,000 cubic feet. The heating system is one of the largest ever installed in New York. It requires 1,320,000 feet

or 25 miles of circulation pipe to distribute the heat properly. All fixtures, counters, tables, partitions and wood finish throughout

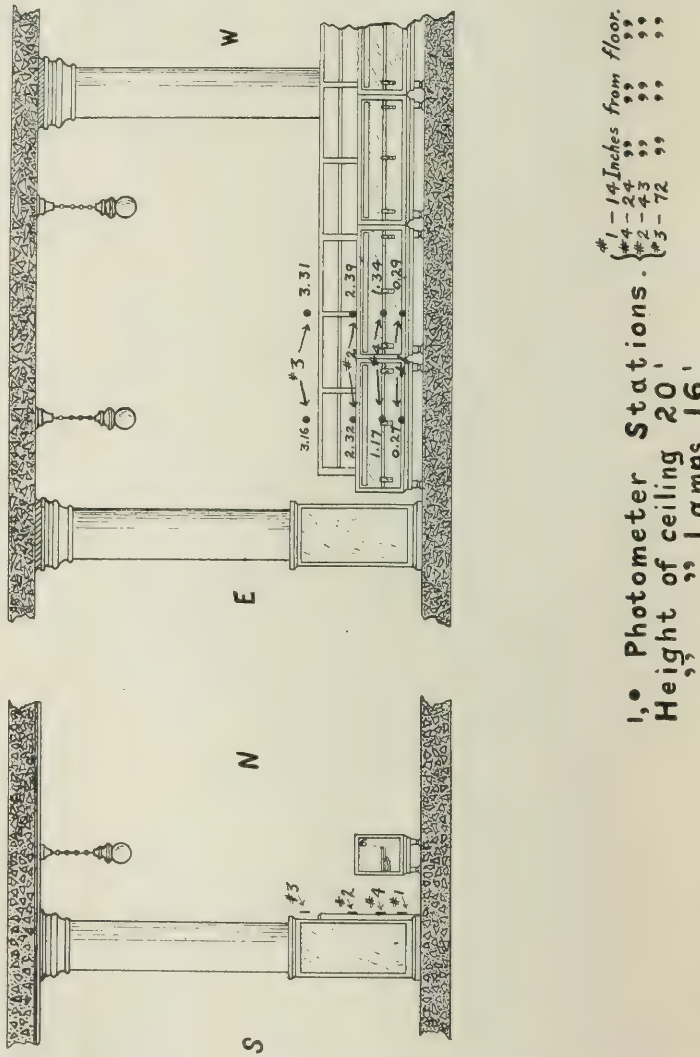

Fig. 3.—Section plan of main floor, (gentlemen's neckwear), showing location of furniture, pillars, lighting units, test stations and illumination data.

the store are of red Mexican mahogany. More than 1,000,000 feet of such lumber were used. Of these fixtures there are 908

show cases, having a combined length of 8,205 feet, 848 wall cases, running 7,652 feet; and 1,376 counters extending 12,642 feet. In addition to these, there are used for displaying stock 985 tables which would, if placed end to end, extend 8,865 feet.

Before proceeding to a discussion of the lighting of this building, the authors desire to congratulate the architects for their

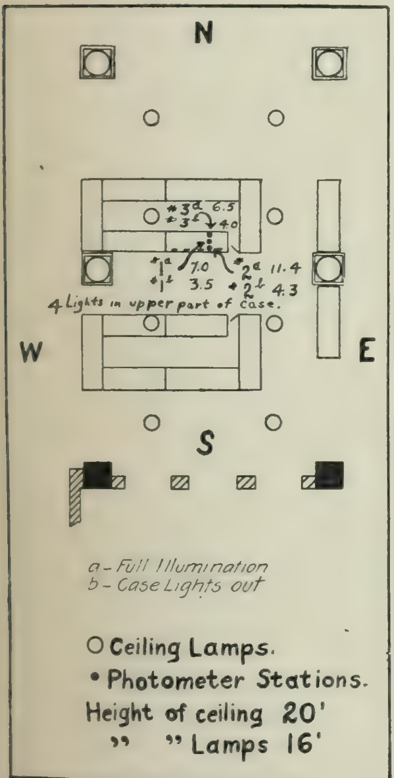

Fig. 4.—Section plan of main floor, (plated silver ware), showing location of furniture, pillars, lighting units, test stations and illumination data.

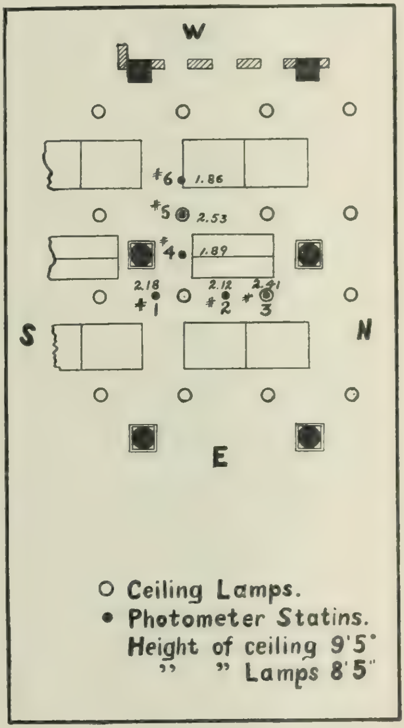

Fig. 5.—Section of main floor, (ladies' untrimmed hats), showing location of furniture, pillars, lighting units, test stations and illumination data.

arrangement (spacing)—of the lighting outlets which permits of ideal light and illumination results being obtained. The outlets are on about 12-feet centers.

A comparatively short time before the completion of this building, the writers were called upon to look over the scheme

of lighting, which, for the most part, had been prepared by an engineer, which scheme, in general, consisted of single pendant chain stem and close fitting ceiling fixtures, using tungsten lamps and equipped with glass spheres of a yellowish orange nature. After carefully ascertaining the requirements of store light-

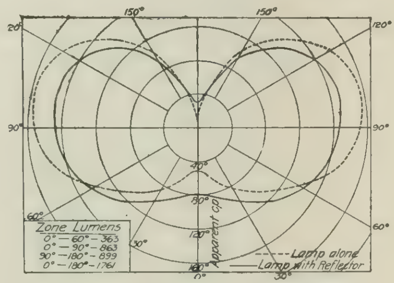

Fig. 7.—Photometric curve of lighting unit used at first on first floor, with frosted tip tungsten lamp.

Fig. 6.—Lighting fixture used on first floor.

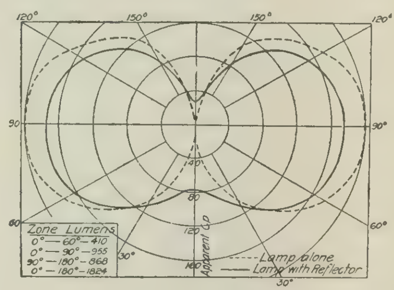

Fig. 8.—Photometric curve of lighting unit now used on first floor, with clear bulb lamp.

ing, and this store in particular, and having made an analysis of the lighting specifications aforementioned, the authors submitted a report to the owners, the gist of which follows:

CONSIDERATIONS.

The first points to be considered in the design of this lighting system are:

First, the effect that is to be produced, that is, the quantity, character, intensity and distribution of illumination.

Second, the lighting scheme should be of such a nature that

neither the light sources, nor the effects produced, will be injurious, or objectional, to the eye.

Third, the light and illumination effects obtained should produce the desired psychological results.

Fourth, the lighting units employed should be effective and harmonious with their surroundings, but not necessarily objects of art, to the point of detracting from the goods on sale.

Fifth, the light sources used should be efficient.

Sixth, the installation should permit of economic maintenance.

CRITICISMS.

The following criticisms are based on eight fixture designs, alphabetically indicated as A, B, C, D, E, F, G and H, and models evolved from some of these designs on display at Gimbel Brothers' Philadelphia establishment. All the designs indicated were purely suggestive and, therefore, being in the rough, were not susceptible to rigid aesthetic criticism.

The over-all drop of the A fixture, (that is, the distance from the ceiling to the extreme bottom of the unit) was seemingly correct from a symmetry point of view for use on the first floor. In connection with this fixture a 12-in. yellow orange tinted ball was indicated, having a 6-in. opening, which opening is too small for the passage of the three 100-watt tungsten lamps which have been specified for use therein. The use of three or more lamps in such cluster formation is inefficient. This is understood when it is known that the lamps, by being in such relative positions, intercept a certain portion of the light rays emanating from one another, thereby preventing a considerable amount of the light flux from striking the interior sides of the ball, thereby resulting in unwarranted absorption. Besides, with the use of three lamps, unless the glassware is exceedingly dense, causing great loss by absorption, three points, or spots of light will be visible on the sphere, thus destroying its symmetry. The use of lamps in this manner, in this unit, should not be considered.

As regards distribution of light flux: the distribution of light about a bare, clear, incandescent electric lamp is, usually, greatest in a horizontal direction, when the lamp is hung pendant; end-on, and those angles between 0° (end-on) and 90° (horizontal)

from which useful illumination is obtained, the flux is not so great. This is corrected by the use of properly designed reflectors. The distribution of light rays about a lamp, when

Fig. 9.—Balcony, main floor mezzanine, showing manicuring tables.

Fig. 10.—Balcony, main floor mezzanine, showing chiropodists' and hair-dressing rooms.

equipped with a diffusing globe, which has comparatively no redirecting qualities, is comparable to that of a bare lamp with the difference that as the diffusing glassware, in order to diffuse light, absorbs a certain percentage of the light flux, depending upon its density, contour, character of surfaces and color, the

illuminating ability of the unit is decreased. If, on the first floor of the New York store, unit A would be used, the ceiling and upper parts of this floor, where no goods are displayed, would be considerably brighter than the shelving and counters, where goods are displayed. The absorption of light by a glass globe, as before indicated, depends on its density, contour, character of

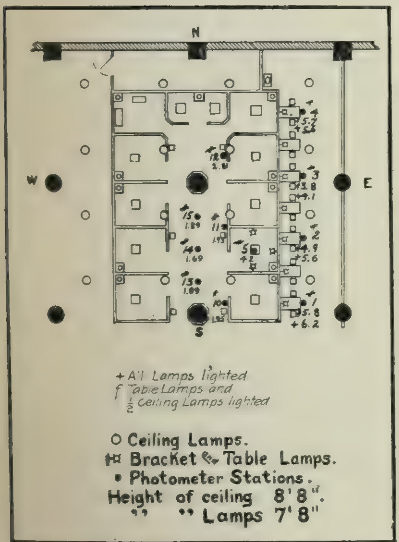

Fig. 11.—Section plan of main floor mezzanine, showing location of hair-dressing and manicuring parlors, lighting units, test stations and illumination data.

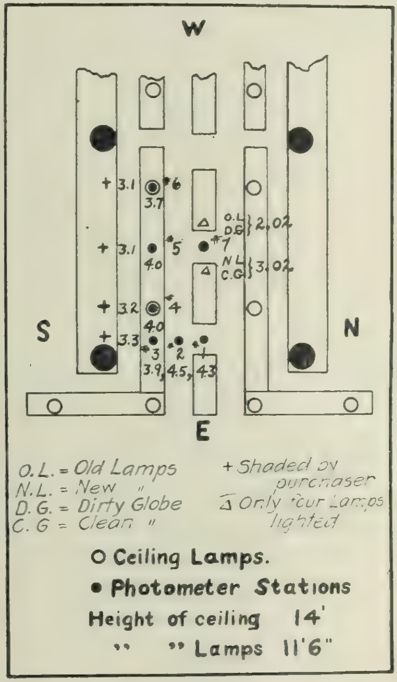

Fig. 12.—Section plan of second floor, (infants' wear), showing location of furniture, pillars, lighting units, test stations and illumination data.

surfaces and color. Following are some figures relative to absorption factors which probably, at this point, will be of interest:

TABLE I.—LIGHT ABSORPTION IN PER CENT.

Clear glass	5 to 10
Ground glass	20 to 30
Alabaster glass	20 to 50
Opal glass	25 to 60
Milk glass	30 to 80

The foregoing factors vary with different qualities and treat-

TABLE II.—COLOR DISTRIBUTION.

Original Color of Fabric	Color of Light: Red	Orange	Yellow	Green	Blue	Violet
Black	Purplish black	Deep maroon	Yellow olive	Greenish brown	Blue black	Faint violet black
White	Red	Orange	Light yellow	Green	Blue	Violet
Red	Intense red	Scarlet	Orange	Brown	Violet	Red violet purple
Orange	Orange red	Intense orange	Yellow orange	Faint yellow slightly greenish	Brown slightly violet	Light red
Yellow	Orange	Yellow orange	Orange yellow	Yellowish green	Green	Brown tinged with faint red
Light green	Reddish gray	Yellow green	Greenish yellow	Intenser green	Blue green	Light purple
Deep green	Reddish black	Rusty green	Yellowish green	Intenser green	Greenish blue	
Light blue violet	Violet	Orange gray	Yellowish green	Green blue	Vivid blue	
Deep blue		Gray slightly orange	Green slate	Blue green	Intenser blue	Bright blue violet
Indigo blue		Orange maroon	Orange yellow (very dull)	Dull green	Dark blue indigo	Deep blue violet
Violet	Purple	Red maroon	Yellow maroon	Bluish green brown	Deep bluish violet	Deep violet

ments of glass and with illuminants giving color values and are to be considered as but representing approximate values.

The glassware specified for the store is of a distant yellow orange tinge, which would not only very materially absorb the light, resulting in a larger consumption of electricity than is nec-

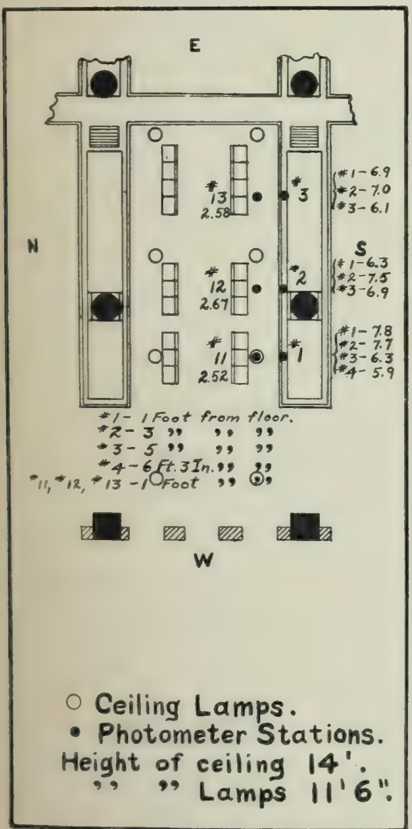

Fig. 13.—Section plan of second floor, (shoe department), showing location of furniture, pillars, lighting units, test stations and illumination data.

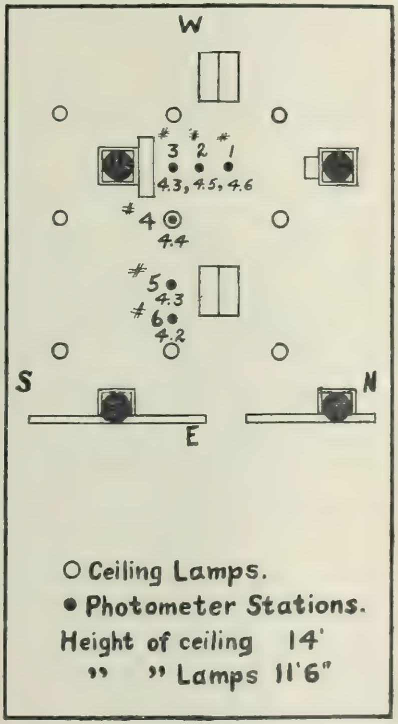

Fig. 14.—Section plan of third floor, (ladies' reception room), location of furniture, pillars, lighting units, test stations and illumination data.

essary but by being highly selective in its absorbing qualities (absorbing to a great extent toward the blue end of the visible spectrum), will distort greatly the true color values of the goods displayed, besides giving a gloomy, dull appearance to the store.

Table II will convey some idea of the effect of different colored lights falling on various colored fabrics:

The question of predominating color of illumination to be employed in a department store is of paramount importance and will be dealt with in greater detail later on in that part of this paper headed "Suggestions."

Criticisms similar to those made on unit A apply to unit B with the exception that instead of three 100-watt lamps, one 150-watt lamp is specified, with a corresponding increase in efficiency.

The criticisms on units C and D are similar to those on unit B.

The E fixture was seen only through the medium of a blue print, and, as insufficient knowledge had been gained from such observation, no comment on it will here be made.

The F fixture will serve its purpose as an emergency lighting unit if hung within easy reach.

Fixture G consists of combination gas and electric brackets, the gas part of which seems to be such as to meet requirements. The electrical part, however, has been, to a measure, hooded by a shade which has apparently not been designed with any special reference to the proper distribution of light rays, nor is it proportionately correct from an aesthetic viewpoint. If similar kind of glass is recommended for this fixture as for fixture A then similar criticisms are in order.

Fixture H is similar to the electric part of fixture C.

SUGGESTIONS—FIRST SCHEME.

First Floor:—Each of the outlets on the first floor should be equipped with one 250-watt bowl-frosted tungsten lamp and prismatic intensive reflector satin-finished; the unit to be attached to the ceiling by a chain fixture. The over-all drop of this fixture should be between 4.0 and 4.5 ft.

Second and Third Floors and Basement Court:—Each ceiling outlet on the second and third floors and basement court between columns 158 and 154 and 139 and 143 should be equipped with 150-watt bowl-frosted tungsten lamp and prismatic intensive reflector, satin-finished, the unit to be attached to the ceiling by a chain fixture. The over-all drop of the fixture for the base-

ment court, should be 4.0 ft., that for the second floor 2.5 ft. and that for the third floor 2.0 ft.

Fourth to Eighth Floors, Inclusive:—Each of the outlets on these floors should be equipped with one 150-watt bowl-frosted tungsten lamp and prismatic intensive reflector, satin-finished, the unit to be attached to the ceiling by a chain fixture. The over-all drop should not exceed 2.0 ft., being preferably from 18 to 20 in.

Basement, Basement Mezzanine, under and over First Floor Mezzanine, Ninth and Tenth Floors, also Toilets, Locker-rooms, and Stairs:—Each of the outlets in these various parts of the building where unit D on architects' drawing was intended, should be equipped with one 150-watt bowl-frosted tungsten lamp and prismatic intensive reflector, satin-finished, the unit to be directly attached to the ceiling by a short fixture. The over-all drop of the lighting fixture should be approximately 10 in. Each socket in the straight electric brackets, as well as in the combination gas and electric, fixtures should be equipped with one 40-watt frosted tip tungsten lamp and prismatic asymmetrical globe in standard 2.25-in. holder position.

SUGGESTIONS—SECOND SCHEME.

First Floor:—Each of the ceiling outlets on first floor should be equipped with one 250-watt clear tungsten lamp and prismatic

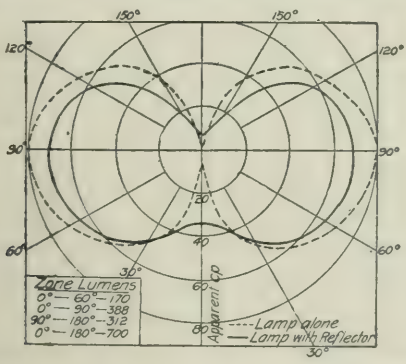

Fig. 15.—Photometric curve of unit now used in parts of the second and first floors.

reflector-ball, the lower hemisphere of which should be satin-finished; the unit to be attached to the ceiling by means of a chain fixture. The overall drop should be 4.5 ft.

Fig. 16.—Lighting unit used on second and third floors.

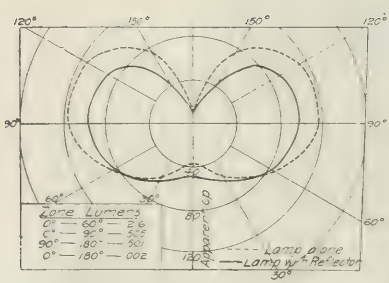

Fig. 17.—Photometric curve of unit installed on second and third floors.

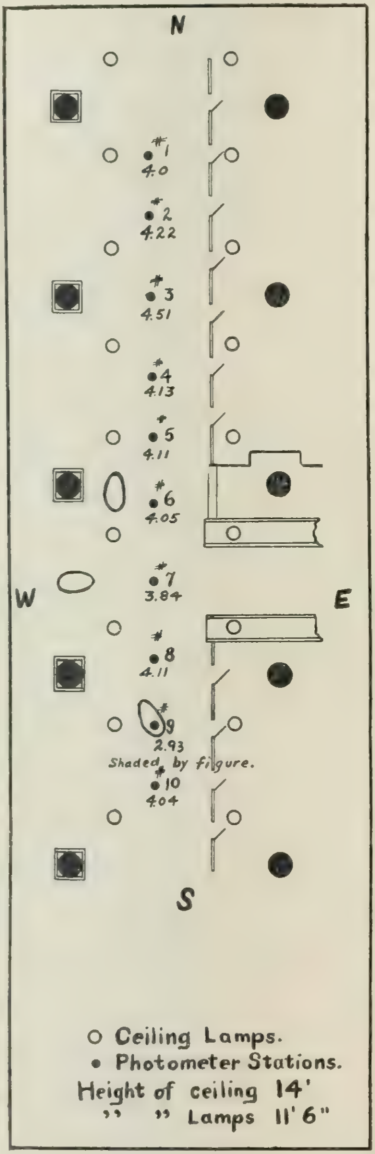

Fig. 18.—Section of third floor, (ladies' cloak and suit department), showing location of furniture, pillars, lighting units, test stations and illumination data.

Second to Eighth Floors, Inclusive:—Each of the ceiling outlets on these floors should be equipped with one 150-watt clear tungsten lamp and prismatic reflector-ball, the lower hemisphere of which should be satin-finished, the unit being attached to the ceiling by means of chain fixture. The overall drop of the fixture for the second floor should be 2.5 ft.; and for the third to eighth floors, inclusive, the drop should be 2.0 ft.

Basement, Basement Mezzanine, under and over First Floor Mezzanine, Ninth and Tenth Floors, also Toilets, Locker-rooms and Stairs:—Each of the ceiling outlets in these various parts of the building, where unit D on architects' drawing was in-

Fig. 19.—Fourth floor, packing department.

tended, should be equipped with one 150-watt clear tungsten lamp and prismatic reflector-ball, the lower hemisphere of which should be satin-finished, the unit being attached to the ceiling by means of a chain fixture. The overall drop of the fixture should be 17 in.

Each socket, in the straight electric brackets, as well as in the combination electric and gas fixtures, should be equipped with one 40-watt frosted tip tungsten lamp and prismatic asymmetrical reflector globe in standard 2.25-in. holder position.

SUGGESTIONS—THIRD SCHEME.

First Floor:—Each of the outlets on the first floor should be equipped with one 250-watt clear tungsten lamp and special prismatic reflector (collar ground off) resting on the lamp in-

side a 14-in. lightly-ground glass sphere with 10-in. opening, the

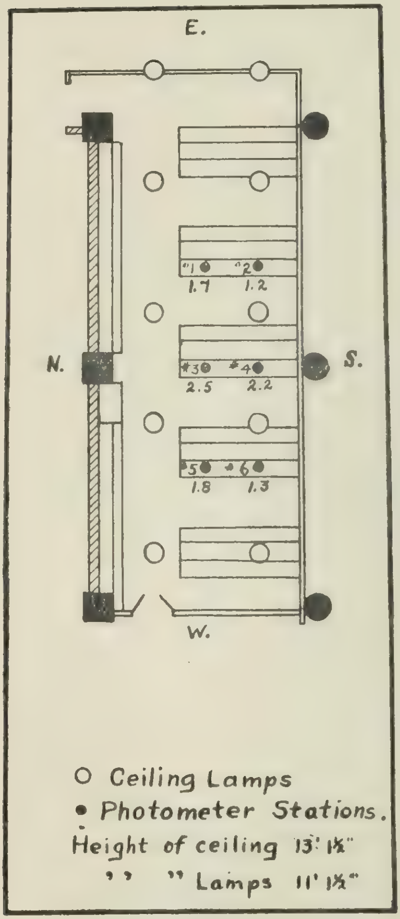

Fig. 20.—Section plan of fourth floor, (packing department), showing location of furniture, pillars, lighting units, test stations and illumination data.

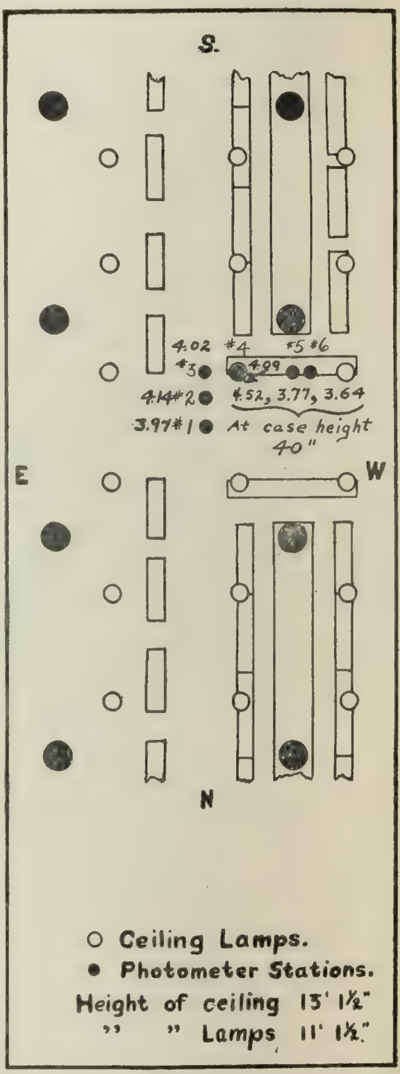

Fig. 21.—Section plan of fourth floor, (gentlemen's hats), showing location of furniture, pillars, lighting units, test stations and illumination data.

unit being attached to the ceiling by a chain fixture. The overall drop of this fixture should be 4.5 ft.

Second to Eighth Floors, Inclusive:—Each ceiling outlet on these floors should be equipped with one 150-watt clear tungsten lamp and prismatic reflector resting on the lamp, inside a 12-in. lightly-ground glass sphere, with 8-in. opening, the unit being attached to the ceiling by means of a chain fixture. The overall drop of the fixture for the second floor should be 2.5 ft. and that for the third to eighth floors inclusive, 2.0 ft.

Each socket in the straight electric brackets, as well as in the

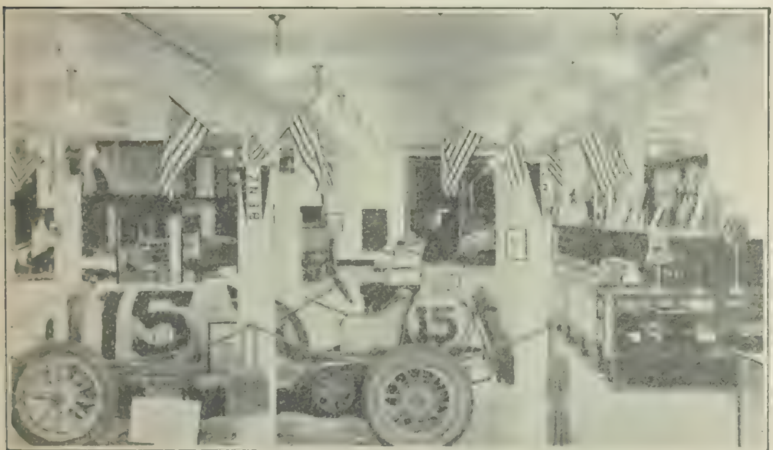

Fig. 22.—Fourth floor, gentlemen's hats.

combination gas and electric fixtures, should be equipped with one 40-watt frosted-tip tungsten lamp and prismatic asymmetrical reflector globe, in standard 2.25-in. holder position.

COMPARISON OF SUGGESTED PLANS.

From Scheme No. 1 on the first floor, an illumination of from 10 to 12 foot-candles, on the shelving and counters would be obtained. The intensity of illumination obtained on the first floor of a large department store in the middle west is from 8 to 10 foot-candles. The aforementioned intensity is of a brilliant and inviting nature, materially adding to the advertising value of the store and, on account of the manner in which it would be obtained, would not have objectionable glare features. A store so lighted denotes the company's confidence in the quality of its goods. Inasmuch with this equipment as the rays of the tungsten lamp

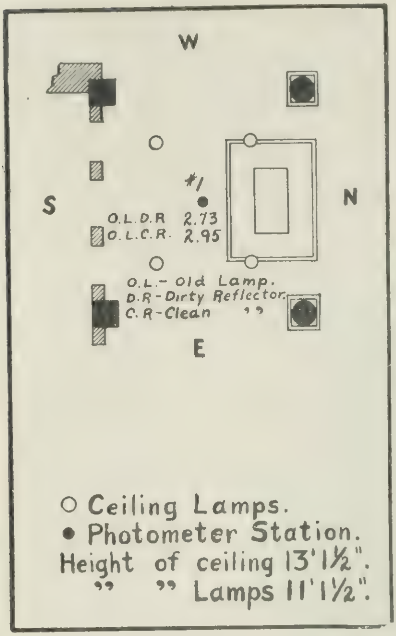

Fig. 23.—Section plan of fourth floor, (toy department), showing location of furniture, pillars, lighting units, test stations and illumination data.

Fig. 24.—Lighting unit used in basement under balcony on fourth and seventh floors.

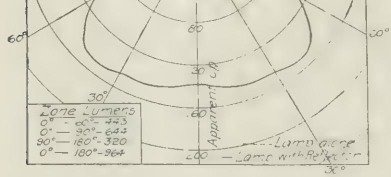

Fig. 25.—Photometric curve of opal reflector with 150-watt bowl-frosted tungsten lamp.

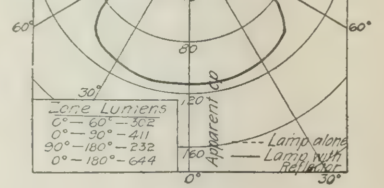

Fig. 26.—Photometric curve of opal reflector with 100-watt bowl-frosted tungsten lamp.

would be reflected, with very little modification, to the working plane, the quality and color of the light would be maintained. On the upper floor where 150-watts per outlet are to be used an illumination intensity of from 8 to 10 foot-candles would be obtained. Scheme No. 1, everything considered, is easily the best proposition to entertain. Scheme No. 2 carries out the ball idea and is considerably more effective and efficient than the use of ordinary diffusing spheres, in that the balls suggested are scientifically constructed, the upper half consisting of a series of totally-reflecting prisms which assist in redirecting the light rays through the satin-finished lower half, thus giving rise to well-diffused, efficient illumination. The chief drawback of an installation of these balls is that the 12-in. sphere (unless it is desired to go to the expense of installing 14-in. spheres on the first floor) would have to be used throughout the several floors inasmuch as the next smaller size prismatic reflector-ball has not a sufficiently large opening to permit the use of 150-watt Tungsten lamps. Scheme No. 3 is the one for ground glass spheres, and is similar to that specified by the engineer with the difference that instead of using on the first floor, three lamps inside of each sphere, one is used; over this lamp there should be placed a reflector which, by directing the light rays to points below the horizontal, would increase materially the useful illumination on the working plane. On the upper floors this same general idea could be carried out, but a 150-watt lamp is recommended instead of the 250-watt.

In order that some tangible idea may be formed of the relative values of the systems here considered, such systems are compared one with another, using Scheme No. 1, as representing 100 per cent. efficiency. These values indicate approximately the relative per cent. of illumination produced on the goods for equal consumption of electricity.

TABLE III.—EFFICIENCY OF ARRANGEMENTS.

	Per cent.
Clear prismatic reflectors	100
Satin-finished prismatic reflectors	85
Prismatic reflector-balls	55
Light ground glass balls with prismatic reflector inside	40
Light ground glass balls without reflectors	30
Yellow orange tinted balls	25

NOTE:—The aforementioned figures are approximate values.

The quality or character (color) of illumination for use in various departments:—It is a well known fact that goods which are shown off to advantage under an illuminant having a certain color value, appear quite different when displayed under another form of source possessing a different color. In a store where goods of so many different natures are shown, it would appear that the color of light employed, in the various departments, should be of a nature to show the goods to the best possible advantage. As an illustration,—cut glass would appear very dull under an illumination produced by an opal globe, while illuminated with the direct rays of a tungsten lamp it would sparkle, giving off prismatic effects which would

Fig. 27.—Sixth floor, rug department.

materially enhance its beauty. In showing off delicate silks, such as ribbons, etc., it is highly important that conditions approach daylight as near as possible, so that the delicate shades may be matched and shown off as they would actually appear in daylight provided they are to be used by day. Inasmuch, however, as such material is, for the most part, worn in the evening, under artificial lighting, it would appear to be a mistake to purchase goods under daylight conditions, without being able to appreciate how such fabrics would appear when actually used. It is the personal opinions of the writers that it is well to provide a place, easily accessible, where artificial light, approaching daylight, is available for color matching, etc. This, then, would permit the general use of illuminants comparable

in color with those employed in the homes, hotels, theatres, etc., where the material generally would be used. In the clothing departments of many stores, it is ofttimes a difficult matter to distinguish blues and dark greens from blacks, etc., which is a most undesirable condition of affairs. In the carpet department, the yellow and red rays are probably the most effective; and so it goes throughout the entire store. Inasmuch as appearance is of considerable importance it is undesirable to use a number of different kinds of illuminants and accessories; be-

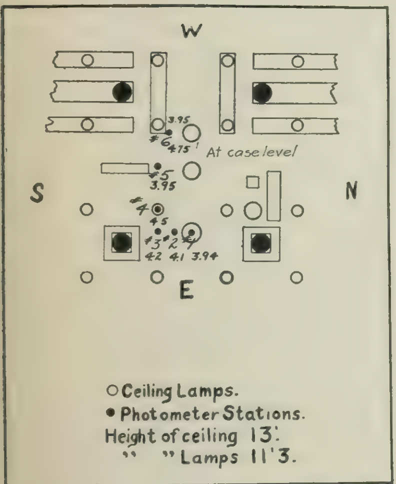

Fig. 28.—Section plan of fifth floor, (kitchen utensils), showing location of furniture, pillars, lighting units, test stations and illumination data.

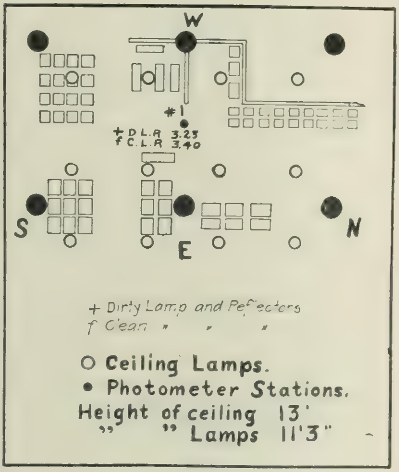

Fig. 29.—Section plan of fifth floor, (household furnishings), showing location of furniture, pillars, lighting units, test stations and illumination data.

sides carrying accessories for such diversified equipment would increase maintenance costs.

To a degree various colors may be obtained from tungsten lamps. Better results are obtained with open reflectors than from enclosing mediums unless such mediums be of clear glass. Such color differences may be had if lamps of different voltages are employed. In explanation of color variation it may be said that a tungsten lamp, say of the 250-watt type, may be operated at what is termed top voltage, middle voltage and bottom voltage. If burned at middle voltage,—standard tungsten lamp light quality, or color, will be obtained.

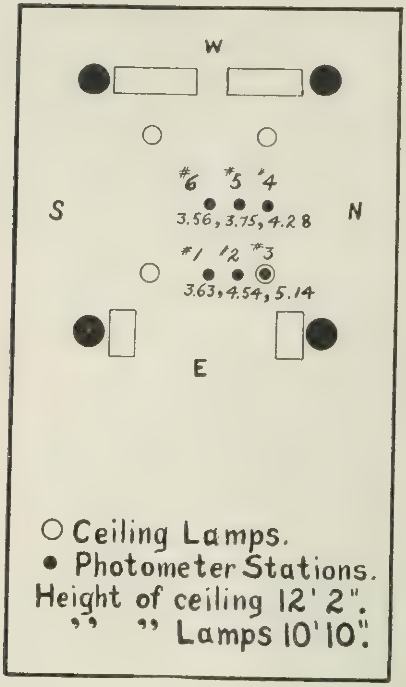

Fig. 30.—Section plan of sixth floor, (rug department), showing location of furniture, pillars, lighting units, test stations and illumination data.

Fig. 31.—Lighting unit used in basement mezzanine, fifth and sixth floors.

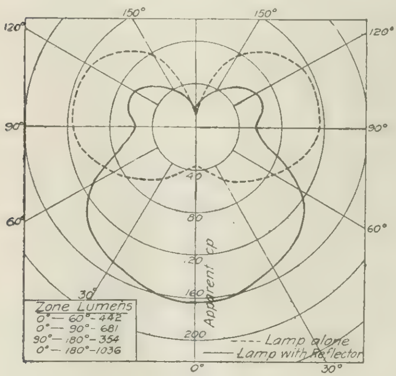

Fig. 32.—Photometric curve of satin-finished prismatic reflector with 150-watt bowl-frosted lamp.

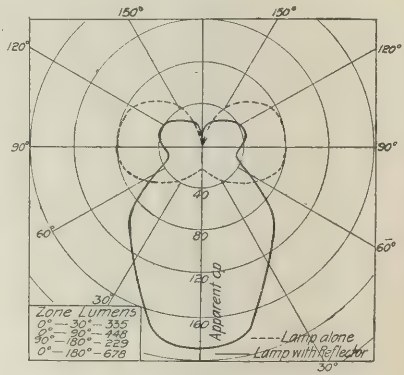

Fig. 33.—Photometric curve of satin-finished prismatic reflector with 100-watt bowl-frosted lamp.

If burned at top voltage a whiter light will be the result with 20 per cent. loss in life, while if burned at bottom voltage a light richer in yellow and red rays will be obtained and the life will be increased by about 23 per cent. Table IV shows the effects of the three voltages on tungsten lamp ruled at 25, 40, 50, 100, 150 and 250 watts.

TABLE IV.—PERFORMANCE OF TUNGSTEN LAMPS AT TOP MIDDLE AND BOTTOM VOLTAGE.

		Top voltage			Middle voltage			Bottom voltage		
Normal rating (Total Watts)	Wattage limits	Watts per candle	Nominal m. h. c-p.	Hours useful and total life	Watts per candle	N. m. h. c-p.	Hours of useful and total life	Watts per candle	N. m. h. c-p.	Hours useful and total life
25 watt..	20 to 34	1.33	18.8	1,000	1.39	17.4	1,300	1.45	16.1	1,700
40 watt.. (small bulb)	34 to 49	1.25	32.0	1,000	1.30	29.9	1,300	1.35	28.0	1,700
40 watt.. (large bulb)	34 to 49	1.25	32.0	1,000	1.30	29.9	1,300	1.35	28.0	1,700
60 watt..	50 to 72	1.20	50.0	1,000	1.25	46.5	1,300	1.30	43.5	1,700
100 watt.	85 to 120	1.15	87.0	800	1.20	80.8	1,000	1.25	75.2	1,300
150 watt.	125 to 175	1.15	130.3	800	1.20	121.1	1,000	1.25	112.8	1,300
250 watt.	200 to 300	1.10	227.3	800	1.15	210.0	1,000	1.20	195.0	1,300

Fig. 34.—Sixth floor, art gallery showing oil paintings.

Window Lighting.—Unquestionably the most efficient and economic manner of lighting windows is through the medium of

lamps equipped with individual reflectors, inasmuch as by the use of scientifically-designed reflectors, the greatest percentage of light flux emanating from a bare lamp is re-directed in the most useful directions, whereas if a so-called trough reflector is used, and the lamps are not individually treated, the reflection becomes more general and less specific. Individual reflectors should

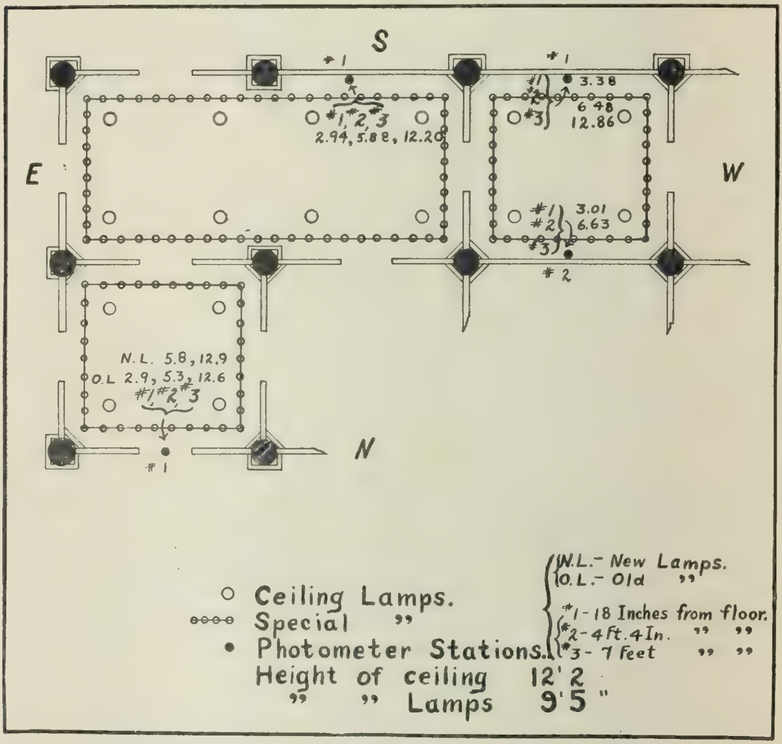

Fig. 35.—Section plan of sixth floor, (art gallery), showing location of furniture, pillars, lighting units, test stations and illumination data.

be used in windows for the same general reasons that single lamps should be used inside of spheres, because where two or more lamps are used under a reflector, a portion of light rays emanating from one lamp is intercepted by the other lamp and is thereby, to a measure, wasted. The individual steel reflector should be placed at the angle formed by the ceiling and front glass, a valance suspended from the ceiling, between reflectors

and plate glass window, will hide the lighting equipment, thereby making the windows more pleasing.

Elevators.—It is highly important that sufficient illumination be provided on floors of elevators so that passengers can readily see the position of the elevator floor when entering or leaving the car, thus considerably eliminating causes for accidents. In order that an illuminating unit could be suggested for the elevators, which would harmonize with their design, and at the same time produce the necessary illumination on the floor, further data would have to be supplied. Too much stress cannot be laid upon the necessity of giving thought to this phase of the lighting installation. This is a detail that in a great number of

Fig. 36.—Fifth floor, cut glass department.

buildings is almost entirely overlooked, with the result that the lighting units which are suggested are woefully inadequate.

General Notes.—It is respectfully suggested that, in deciding on the lighting installation for this establishment, the advances which have been made in the art and science of illuminating engineering during the last few years be considered so that such development may be employed advantageously in this store. Numerous lighting equipments installed in stores have been designed with only a few hit or miss ideas of their illuminating value, and it is hardly necessary to state that a number of these installations, proving inadequate, have been discontinued and more modern arrangements installed in their place, in some instances at a cost of many thousand of dollars.

Fig. 37.—Seventh floor, furniture department.

After the aforementioned recommendations had been made, it was learned that the contract for the lighting fixtures had already been let. The fixture manufacturers, being approached by the owners to see if some changes could not be affected along lines suggested by the authors, very kindly agreed to do all in their power to obtain the desired results. Inasmuch, however, as arrangements had already been made for a considerable part of the lighting equipment it was impossible to carry out the suggestions wholly. The changes made were the use of

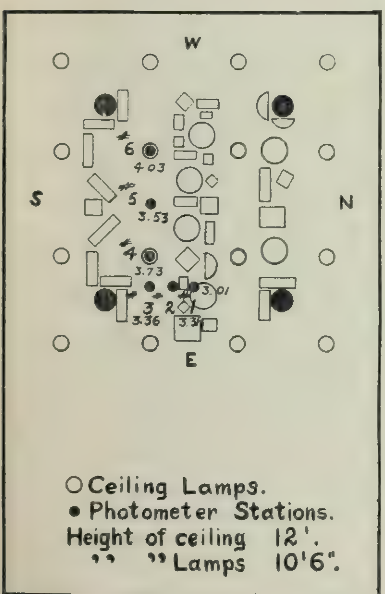

Fig. 38.—Section plan of seventh floor, (furniture department), showing location of furniture, pillars, lighting units, test stations and illumination data.

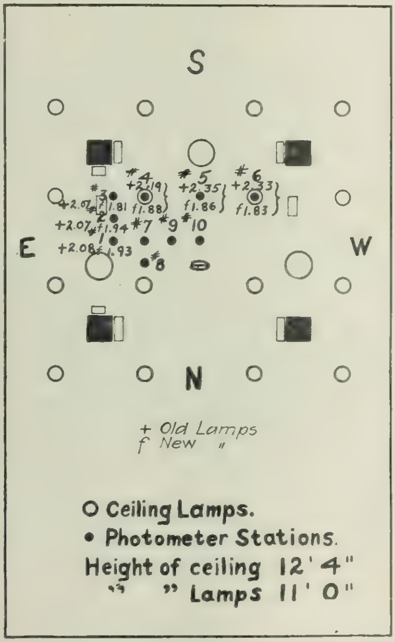

Fig. 39.—Section plan of eighth floor, (main restaurant), showing location of furniture, pillars, lighting units, test stations and illumination data.

lightly-ground glass 14-in. balls with single units on the first floor, instead of the yellow orange tinted glass-ball with three lamps, as suggested by the engineer; the use of 10-in. ground glass-balls, instead of the tinted sphere in the basement, main floor under balcony, main floor mezzanine; second, third, floor as suggested by the engineer; the use of 10-in. ground

glass-balls instead of the tinted sphere in the basement, main floor under balcony, main floor mezzanine; second, third, eighth floors; the use of opal reflectors in basement, under balcony, fourth and seventh floors; prismatic reflectors in basement mezzanine; fifth and sixth floors, with individual steel reflectors in the art galleries and display windows.

SUPPLY OF ENERGY.

For supplying energy for the large connected lamp and motor load in the building, the rating of which aggregates approxi-

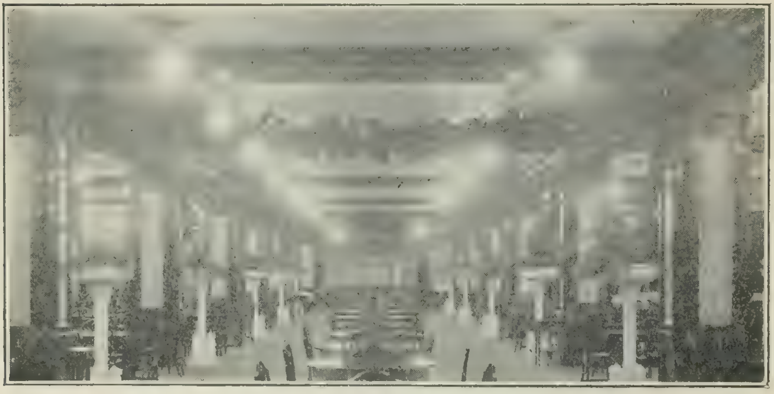

Fig. 40.—Eighth floor, main restaurant.

mately 10,000 hp., the New York Edison Company erected a substation in the sub-basement. The equipment installed consists of seven 1,000-kw. rotary converters with the necessary step-down transformers and high-tension switches. Three-phase, 25-cycle alternating current, at a tension of 6,600 volts, is brought under-ground from the Waterside stations, and this is converted to direct current at a potential of 240 volts for the three-wire system in the building. A direct-current switchboard located in the sub-basement is joined with the building distribution board by heavy tie connections. In addition there are several 1,000,000-circ. mil concentric cables for connection with the Edison distribution mains, so that in case of trouble with the substation apparatus these feeders will supply energy

from the street service to the building, thus ensuring continuity of service under all conditions. Aside from taking care of the lighting load, the Edison service is also used for thirty-six passage elevators and ten freight elevators.

ILLUMINATION TESTS.

After the opening of the Gimbel store, the New York Edison Company authorized the Electrical Testing Laboratories of New York, to conduct illumination and other tests in this building, in order to arrive at a knowledge of the results which were actually being obtained. These tests, which were conducted during a period of several weeks, were made under the immediate super-

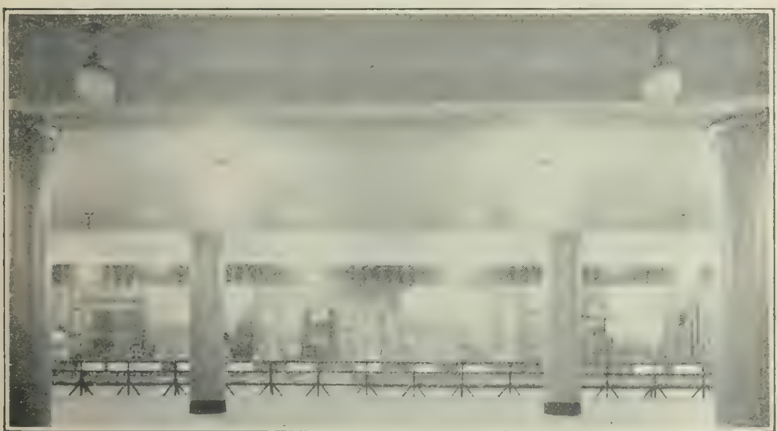

Fig. 41.—Eighth floor, auditorium.

vision and direction of the authors. Tests were made in various parts of the store, each test station being represented by a plan or elevation. Upon these diagrams, test stations have been indicated and the illumination at each station has been shown in foot-candles; with a few exceptions, there is a diagram for each area. Measurements were made in horizontal and vertical planes as directed. The test stations were located with a view of securing the most typical and most useful values, rather than with a view of determining the total flux on any given plane through measurements at equally spaced stations. In all test areas except as noted, the lighting was provided by means of tungsten lamps;

various kinds of glassware were employed; the voltage at which the lamps were operating during the tests was determined by means of photometric measurements at the sockets. To facili-

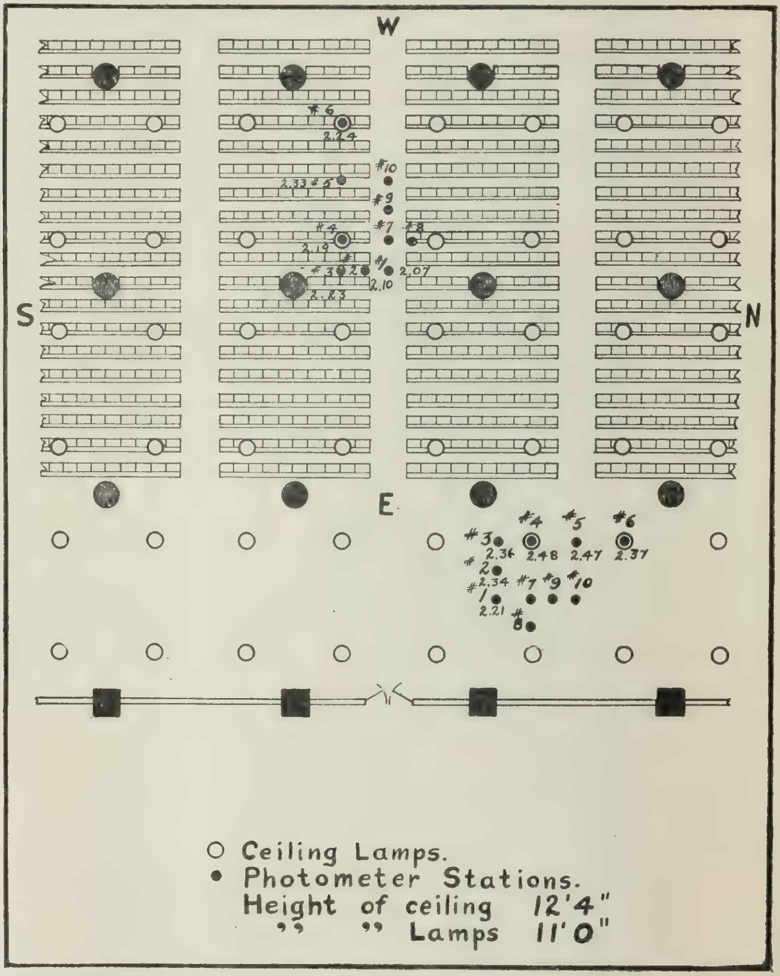

Fig. 42.—Section plan of eighth floor, (auditorium), showing location of furniture, pillars, lighting units, test stations and illumination data.

tate comparisons among the various tests, all values of candle-power and foot-candles have been corrected for variation from 120 volts at the lamp socket. The lamps and glassware were

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TABLE V.

Test area: Floor	Test area: Department	Test area: Ceiling height	Lighting installation: Light source. All tung. lamps	Lighting installation: Auxiliary	Lighting installation: Light source above floor	Flux expressed in lumens: Light source alone, Total: Assumed when new	Measured at 120 volts	Per cent. Difference	Assumed when new, In stated zones: 0° to 60°	Lower hemisphere 0° to 90°	Upper hemisphere 90° to 180°	Total sphere 0° to 180°	Measured at 120 volts, In stated zones: 0° to 60°	Lower hemisphere 0° to 90°	Upper hemisphere 90° to 180°	Total sphere 0° to 180°	Height of reference plane, inches	Horizontal foot-candles: All lamps lighted: Minimum	Approx. mean	Maximum	Normal number lamps lighted: Minimum	Approx. mean	Maximum	Remarks
Basement under balcony	China	9 ft. 3 in.	100-watt bowl frosted	150-watt opal refl.	8 ft. 5 in.	794	686	— 14	302	411	232	644	260	353	199	553	33	3.0	3.6	4.3	..	..	..	
Basement (in well)	Notion	21 ft. 10 in.	150-watt bowl frosted	10-in. ground glass ball	17 ft. 2 in.	1192	822	—31	216	505	501	1006	149	349	346	695	33	2.8	3.0	3.1	..	..	..	
Basement mezzanine	Dairy lunch room	9 ft.	100-watt bowl frosted	150-watt prismatic refl.	8 ft. 2 in.	794	753	— 5	335	448	229	678	318	426	218	644	33	2.7	..	7.7	..	..	..	
Main under balcony	Ladies' untrimmed hats	9 ft. 5 in.	60-watt bowl frosted	10-in. ground glass ball	8 ft. 5 in.	477	426	—11	97	223	192	415	86	198	171	369	33	1.9	2.2	2.5	..	..	..	
Main mezzanine	Manicuring parlors	8 ft. 8 in.	60 and 100-watt clear and bowl frosted	10-in. ground glass ball	7 ft. 8 in.	477	426	—11	97	223	192	415	86	198	171	369	30	4.1	..	6.2	3.8	..	5.8	
Main mezzanine	Corridor between hair dressing parlors	8 ft. 8 in.	60-watt clear and bowl frosted	10-in. ground glass ball	7 ft. 8 in.	477	426	-11	97	223	192	415	86	198	171	369	40	1.7	2.0	2.8	..	..	..	
Main	General	20 ft.	250-watt bowl frosted	14-in. ground glass ball	16 ft.	1986	1560	21	363	863	899	1762	287	682	710	1392	33	8.9	9.3	9.8	5.1	5.5	6.2	
Second	Infants' wear	14 ft.	150-watt bowl frosted	10-in. ground glass ball	11 ft. 6 in.	1192	855	—28	216	505	501	1006	156	364	361	725	33	3.7	4.1	4.5	..	..	..	Presence of purchaser at counter found to reduce intensity by about 25 per cent.
Second	Shoe	14 ft.	150-watt bowl frosted	10-in. ground glass ball	11 ft. 6 in.	1192	942	—21	216	505	501	1006	171	399	396	795	12	2.5	2.6	2.7	..	..	..	
Third	Ladies' reception room	14 ft.	150-watt bowl frosted	10-in. ground glass ball	11 ft. 6 in.	1192	855	—28	216	505	501	1006	156	364	361	725	33	4.2	4.4	4.6	..	.	..	
Third	Ladies' cloaks and suits	14 ft.	150-watt bowl frosted	10-in. ground glass ball	11 ft. 6 in.	1192	879	-26	216	505	501	1006	160	374	371	745	33	3.8	4.1	4.5	..	..	..	
Fourth	Gentlemen's hats	13 ft. 1½ in.	150-watt bowl frosted	150-watt opal refl.	11 ft. 1.5 in.	1192	863	—28	443	644	320	964	319	464	231	694	33 40	4.0 3.6	4.1 4.0	4.1 4.5	.. ..	.. ..	.. ..	Four stations 33 in. Three stations 40 in. (Height.)
Fourth	Packing room	13 ft. 1½ in.	150-watt bowl frosted	150-watt opal refl.	11 ft. 1.5 in.	1192	789	—34	443	644	320	964	292	425	211	636	35	1.3	..	2.5	..	..	..	
Fifth	Kitchen utensils	13 ft.	150-watt bowl frosted	150-watt prismatic refl.	11 ft. 3 in.	1192	859	—28	442	681	354	1036	318	490	255	746	33	3.9	4.1	4.5	..	..	..	
Sixth	Rug	12 ft. 2 in.	100-watt bowl frosted	150-watt prismatic refl.	10 ft. 10 in.	794	753	— 5	335	448	229	678	318	426	218	644	33	3.6	4.1	5.1	..	..	..	
Seventh	Furniture	12 ft.	100-watt bowl frosted	150-watt opal refl.	10 ft. 6 in.	794	733	— 8	302	411	232	644	278	378	213	593	33	3.0	3.5	4.0	..	..	..	
Eighth	Auditorium	12 ft. 4 in.	60-watt bowl frosted	10-in. ground glass ball	11 ft.	477	473	— 1	97	223	192	415	96	221	190	411	33	2.1	2.2	2.3	..	..	..	
Eighth	Auditorium	12 ft. 4 in.	60-watt bowl frosted	10-in. ground glass ball	11 ft.	477	473	— 1	97	223	192	415	96	221	190	411	33	2.2	2.4	2.5	..	..	..	
Eighth	Smoking room	12 ft. 4 in.	60-watt bowl frosted	10-in. ground glass ball	11 ft.	477	467	— 2	97	223	192	415	95	219	188	406	33	2.0	2.05	2.1	..	..	..	
Eighth	Restaurant (main room)	12 ft. 4 in.	60 and 100-watt bowl frosted	10-in. ground glass ball	11 ft.	477	440	— 8	97	223	192	415	89	205	177	382	33	2.1	2.2	2.3	..	..	..	
Eighth	Restaurant (main room)	12 ft. 4 in.	60-watt bowl frosted	10-in. ground glass ball	11 ft.	477	440	— 8	97	223	192	415	89	205	177	382	33	1.8	1.9	1.9	..	..	..	
Sixth Avenue	Main entrance	20 ft.	Three 150-watt bowl frosted (in cluster)	16-in. ground glass ball	16 ft.	..	..	..	..	..	..	..	..	..	..	..	33	2.6	3.0	3.4	..	..	..	
33d Street	Outside shipping	13 ft. 4 in.	100-watt bowl frosted	14-in. flat opal refl.	11 ft. 0.5 in.	..	..	..	..	..	..	..	..	..	..	..	33	1.5	..	4.4	..	..	..	
			Carbon Lamps																*Special*					
Elevator	No. 41	8 ft. 9 in.	16-c-p. clear	Ground glass hemisphere	......	..	..	..	..	..	..	..	..	..	..	..	0 .	.. ..	0.2 0.4	.. ..	.. ..	.. ..	.. ..	Old lamps. New lamps.
Main mezzanine	Hair dressing room	8 ft. 8 in.	Three 16-c-p. clear	Deep frosted glass shades	......	..	..	..	..	..	..	..	..	..	..	..	43	..	4.2	..	..	..	..	(One setting only.)
			Tantalum Lamps																					
Between 2d and 3d	Stairway (typical)	14 ft. 2 in.	25-watt clear	150-watt opal refl. deep frosted glass shade	......	..	..	..	..	..	..	..	..	..	..	..	33	0.25	..	1.5	..	..	..	Opal reflectors over second floor landing. Ground glass shades on wall brackets.

tested as found, except that in some instances, as noted, dust which had accumulated was removed, and a repeated test was made to determine the change.

Six sample lamps from each test were removed to the laboratories for rating test at 120 volts. Sample of each kind of glassware involved in the tests were also brought to the laboratories and there tested with a typical lamp of the type employed, for distribution of light. The information thus obtained from labora-

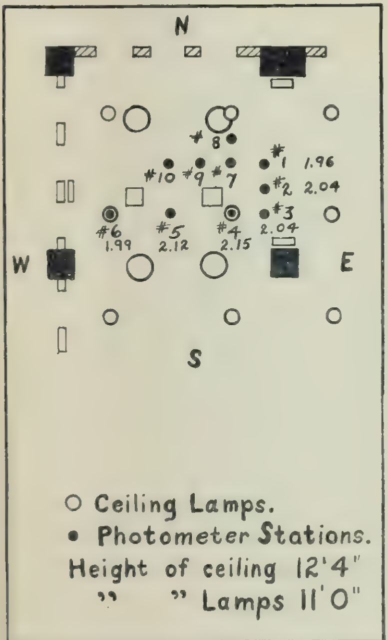


Fig. 43.—Section plan of eighth floor, (smoking room), showing location of furniture, pillars, lighting units, test stations and illumination data.

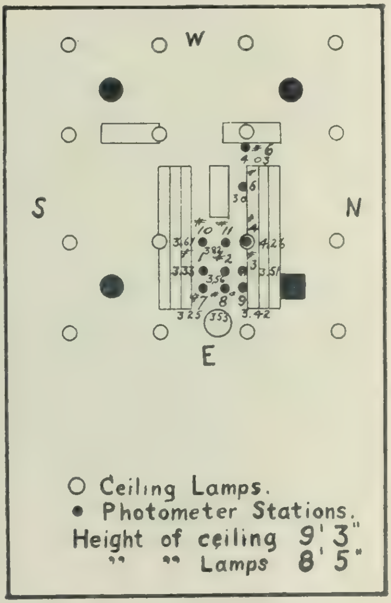


Fig. 44.—Section plan of basement, (china department), showing location of furniture, pillars, lighting units, test stations and illumination data.

tory tests appears with the test data obtained in the store, in Table V which presents information on the following points:

Location of test area; brief description of lighting installation; total lumens of the lamp alone assumed from manufacturer's rating when new, and as measured at 120 volts immediately after the illumination tests; lumens produced by the light source and auxiliary within various indicated zones, both as

assumed for a new lamp and as measured at 120 volts immediately after test; height of reference plane in all measurements of horizontal illuminations, and data on horizontal illumination.

Wherever test stations are so located or the distribution is so uniform that the numerical average of all is thought to yield a fairly representative value, an average of all test station values is shown. These values, however, do not purport to be true mean foot-candles for the test area. In each case the range in intensity is indicated by the minimum and maximum found.

Fig 45.—Fourth floor, toy department.

It is practice on the main floor to operate only about half of the lamps; hence the additional values shown.

NOTES ON TEST AREAS.

Chinaware—Basement.—White ceiling, white pillars, light wood floor, mahogany counters. (Fig. 44.)

Notions—Basement.—White ceiling, white pillars, light wood floor, mahogany cases. (Fig. 49.)

Dairy Lunch Room 9—Basement.—White ceiling, white pillars, light wood floor, mahogany counters. Tests stations in space between counters. (Fig. 48.)

Ladies' Untrimmed Hats—Main Floor.—White ceiling, white pillars, light wood floor, general tone of display, dark. (Fig. 5.)

Manicuring Parlors—Mezzanine Main Foor.—White ceiling, white pillars, dark green carpet, mahogany tables and partition;

16 c-p. carbon lamps with metal reflectors on each table; illumination intensity measured at edges of manicuring tables. (Fig. 11.)

Corridor between Hair Dressing Parlors—Mezzanine Main Floor.—White ceiling, mirrored pillars, dark green carpet, mahogany partition.

General Merchandise—Main Floor.—White ceiling, white pillars, light wood floor, mahogany cases. (Fig. 2.)

Infants Wear—Second Floor.—White ceiling, white pillars, dark green carpet, mahogany cases; light materials displayed. (Fig. 12.)

Fig. 46.—Basement mezzanine, dairy lunch.

Shoe Department—Second Floor.—White ceiling, dark green carpet, mahogany furniture and shelves, light gray shoe boxes. (Fig. 13.)

Ladies Reception Room—Third Floor.—White ceiling, white pillars, dark green carpet, mahogany and green wicker furniture. (Fig. 14.)

Ladies Cloaks and Suits—Third Floor.—White ceiling, mirrored pillars and doors, dark green carpet, mahogany partitions and cases. (Fig. 18.)

Gentlemen's Hats—Fourth Floor.—White ceiling, white pillars, light wood floor, dark cases; dark materials displayed. (Fig. 21.)

Packing Room—Fourth Floor.—White ceiling, white pillars, light wood floor and benches. (Fig. 20.)

Kitchen Utensils—Fifth Floor.—White ceiling, white pillars, light wood floor, white tablecloths on mahogany tables, copper, brass and nickelware displayed. (Fig. 28.)

Rugs—Sixth Floor.—White ceiling, white pillars covered with rugs; floor covered with rugs generally, but cleared locally. (Fig. 30.)

Furniture—Seventh Floor.—White ceiling, white pillars, dark green carpet in center aisle, light wood floor on either side, furniture chiefly mahogany and black walnut. (Fig. 38.)

Fig. 47.—Basement in well.

Auditorium—Eighth Floor.—White ceiling, buff pillars, dark green carpet in center aisle, mahogany stained chairs, light wood floor. Second test similar, except chairs removed. (Fig. 42.)

Smoking-room—Eighth Floor.—Gray ceiling, black walnut finished pillars, decorations in gold, mahogany furniture, white table-cloths on tables, white tiled floors. (Fig. 43.)

Restaurant—Main Room—Eighth Floor.—Gray ceiling, mahogany and gilt pillars, mahogany furniture, dark blue carpet. The second test differs from the first in that the lamps were replaced by new lamps, all of the 60-watt size. (Fig. 39.)

Main Sixth Avenue Entrance.—White ceiling, brown linoleum floor, local illumination augmented by that due to lamps in windows and interior, (half lamps burning). (Fig. 53.)

	…nches	72 inches		84 inches		
	Maximum	Minimum	Maximum	Minimum		Maximum
	..	3.2	3.3	..		..
	..	2.2	2.4	..		..
	..	1.2	2.6	..		..
	..	1.0	2.3	..		..
	..	..	..	..		..
	6.6	.	..	..	12.9	..
9	..	..	..	..	12.2	..
3	..	..	..	..	12.6	..
ry)						
	7.1					

TABLE VI.—VERTICAL ILLUMINATION.

Test area			Lighting installation			Foot-candles—Verticle plane. Height of test stations													
						14 inches		18 inches		24 inches		43 inches		52 inches		72 inches		84 inches	
Floor	Department	Ceiling height	Light source	Auxiliary	Light source above floor	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Main	Gentlemen's neckwear	20 ft.	250 watt bowl frst.	14-in. ground glass ball	16 ft.	0.3	0.3	..	..	1.2	1.3	2.3	2.4	..	..	3.2	3.3	..	..
Second	White goods	14 ft.	150 watt bowl frst.	10-in. ground glass ball	11 ft. 6 in.	0.5	0.6	..	..	1.1	1.2	1.6	1.9	..	..	2.2	2.4	..	..
Fourth	Book	13 ft. 1.5 in.	150 watt bowl frst.	150 watt opal refl.	11 ft. 1.5 in.	0.3	0.5	..	..	0.6	1.0	1.1	1.7	..	..	1.2	2.6	..	..
Fifth	Kitchen utensils	13 ft.	150 watt bowl frst.	Prismatic reflector	11 ft. 3 in.	0.3	0.6	..	..	0.5	0.5	1.0	1.4	..	..	1.0	2.3	..	..
Sixth	Art galleries	12 ft. 2 in.	40 watt clear	Metal reflector	9 ft. 5 in.	..	..	..	..	..	..	..	..	..	..	..	..	..	..
	White room	......	......	......	......	..	..	3.0	3.4	..	..	..	..	6.5	6.6	.	..	.. 12.9	..
	Painting gallery	......	......	......	......	..	..	.. 2.9	..	..	..	..	..	.. 5.9	..	..	..	.. 12.2	..
	Carbon room	......	......	......	......	..	..	.. 2.9	..	..	..	..	..	.. 5.3	..	..	..	.. 12.6	..
						12 in.		36 in.		60 in.		75 in		(Gallery)					
Second	Shoe	14 ft.	150 watt bowl frst.	10-in. ground glass ball	11 ft. 6 in.	6.3	7.8	7.0	7.7	6.1	6.9	5.9		2.2	7.1				

TESTS OF VERTICAL ILLUMINATION.

Table VI shows results of illumination tests in departments where intensity of illumination on the vertical plane was considered to be most indicative of the useful illumination. These measurements were made at various heighths above the floor, as required, in consideration of the objects to be accomplished in the various departments. Only minimum values are given in the summary.

In the installations where alternate rows of lamps are ex-

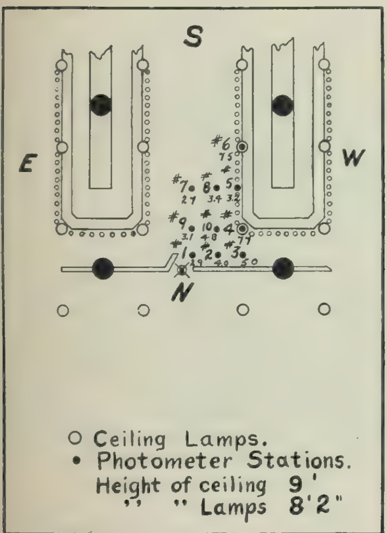


Fig. 48.—Section plan of basement mezzanine, (dairy lunch), showing location of furniture, pillars, lighting units, test stations and illumination data.

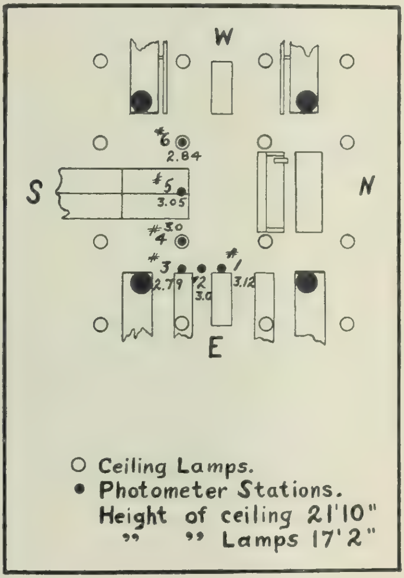


Fig. 49.—Section plan of basement in well, (notion department), showing location of furniture, pillars, lighting units, test stations and illumination data.

tinguished, as noted below, the illumination is, of course, much reduced. When the row of extinguished lamps is parallel with the plane of reference, there is relatively small influence upon the uniformity. This applies to the neckwear and white goods departments.

When the row of extinguished lamps is transverse with respect to the plane of reference, the uniformity is affected unfavorably. Such instances are found in the book and kitchen utensil departments.

NOTES ON TEST AREAS.

Gentlemen's Neckwear—Main Floor.—Half general illumination throughout floor; row of lamps over counter extinguished. (Fig. 37.)

White Goods—Second Floor.—Half general illumination throughout floor; row of lamps over counter in use.

Books—Fourth Floor.—Half general illumination throughout floor; alternate rows of lamps in use.

Kitchen Utensils—Fifth Floor.—Half general illumination throughout floor; alternate rows of lamps burning. (Fig. 28.)

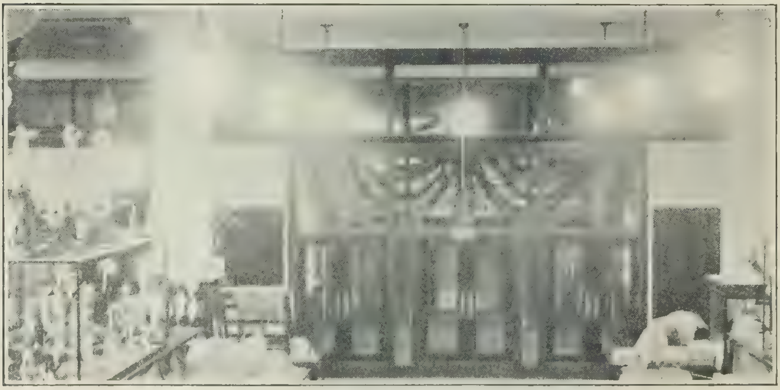


Fig. 50.—First floor, main entrance.

SHOW WINDOW ILLUMINATION.

Window No. 21 was selected for test purposes. The ceiling is 10 ft. 8 in. above the bottom of the show-case, and the lighting is by 60-watt clear tungsten lamps with 30-degrees steel reflectors. The results of the test are indicated in Table VII.

TABLE VII.—SHOW WINDOW ILLUMINATION

Test plane above floor	Foot-candles Horizontal		Normal		Vertical	
Feet	Min.	Max.	Min.	Max.	Min.	Max.
Level	10.7	15.0	11.5	14.9	4.3	6.7
2	15.4	16.7	16.3	17.1	8.0	8.1
4	15.5	18.7	17.8	17.4	13.0	13.6
6	13.8	19.2	23.2	24.0	17.8	19.5

TEST OF LIGHT ABSORPTION DUE TO DUST.

Certain casual tests were made to determine the extent of the improvement effected by cleaning the lamps. These are barely more than suggestive, as only one test station was in-

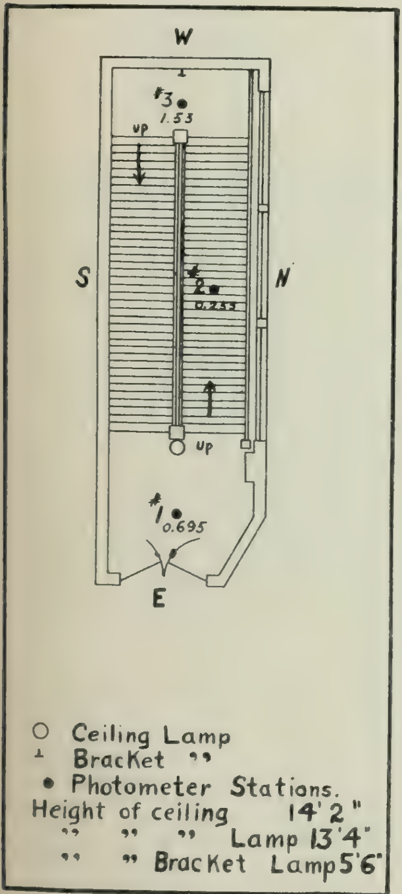


Fig. 51.—Section plan showing typical stairway, showing location of lighting units, test stations and illumination data.

Fig. 52.—Steel reflector used in window on street level.

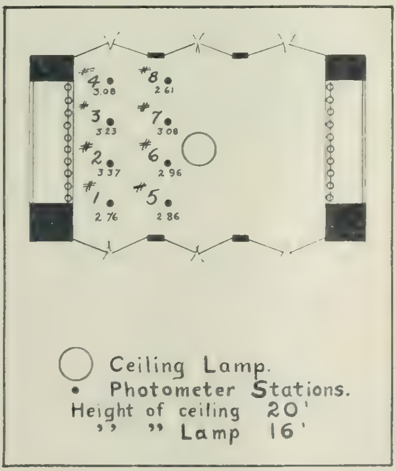


Fig. 53.—Section plan of first floor, (main entrance), showing location of lighting units, test stations and illumination data.

vestigated in each department before and after cleaning the lamps and the glassware. The results of these tests appear in Table No. 8. In addition to these simple tests, the effect of re-

TABLE VIII.—LIGHT ABSORPTION DUE TO DUST.

Test area			Lighting installation				Horizontal foot-candles		
Floor	Department	Ceiling height	Light source	Auxiliary	Light source from floor	Height of test plane	Equipment dusty, old lamps	Equipment clean, old lamps	Equipment clean, new lamps
Main[1]	General merchandise	20 feet	250-watt bowl frosted	14-in. ground glass ball	16 feet	33 in.	2.4	2.8	3.0[2]
Second	Infants wear	14 feet	150-watt bowl frosted	10-in. ground glass ball	11 feet 6 in.	33 in.	2.0	..	3.0
Fourth	Toy	13 feet 1½ in.	150-watt bowl frosted	Opal reflector	11 feet 1½ in.	33 in.	2.7	3.0	..
Fifth	Hardware	13 feet	150-watt bowl frosted	Prismatic reflector	11 ft. 3 in.	33 in.	3.2	3.4	..

[1] Average total lumens, old lamps 1560
[1] Average total lumens, new lamps 2020
[2] Clear lamps.

placing the lamps with new lamps in two of the installation was determined.

It is interesting to note the effect of dust on ground glass balls opal and prismatic reflectors. With the 14-in. ground glass ball the depreciation, in useful illumination, due to the accumulation of dust, is approximately 16 per cent. While it was not convenient to obtain data on the 10-in. ground glass ball of a similar nature, it is reasonable to assume that the loss is approximately the same. With the opal reflector the loss was found to be approximately 11 per cent., while with the prismatic reflectors, the loss was approximately 6 per cent.

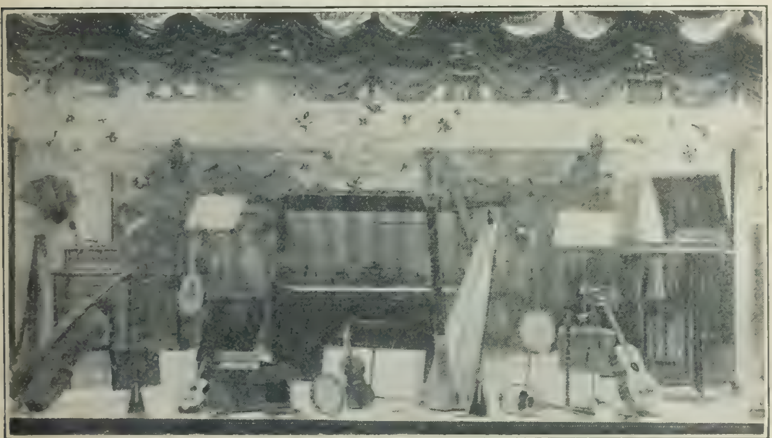


Fig. 54.—Show window lighting.

A further analysis of Table VIII shows that for equal wattage the satin-finished, prismatic reflector gives approximately 14 per cent. greater useful illumination that the opal reflector, and that for equal illumination the satin-finished, prismatic reflector gives approximately twice the useful illumination as that obtained from tungsten lamps enclosed in light ground-glass spheres.

SPECIFIC INTENSITY OF SURFACES.

Certain tests of specific intensity of ceiling, and in one case of shelves, were made. The portion of ceiling investigated was

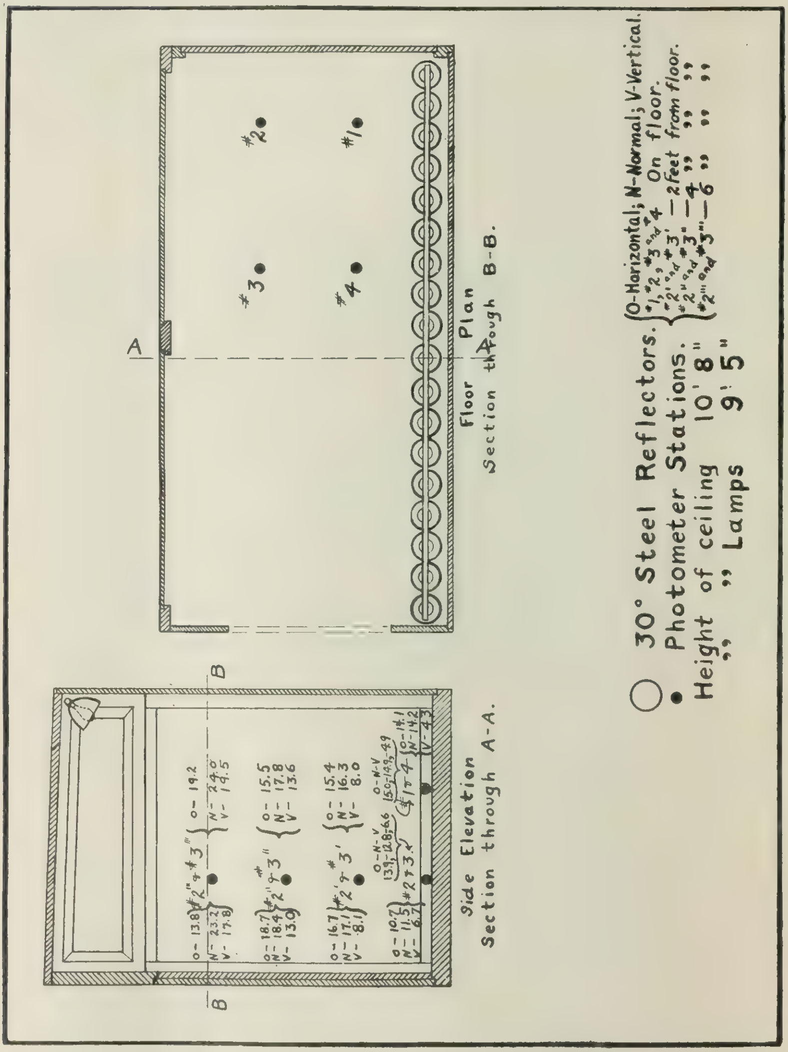


Fig. 55.—Section plan of typical window, showing location of furnishings, lighting units, test stations and illumination data.

TABLE IX.—SURFACE INTENSITIES.

Floor	Department		Specific intensity C-p. per sq. in. Minimum	Maximum	Remarks
Eighth	Smoking-room	Ceiling	0.0015	0.0041	
Eighth	Auditorium	Ceiling	0.0012	0.0037	(Normal condition)
Eighth	Auditorium	Ceiling	0.0021	0.0045	(Chairs removed)
Sixth	Rug	Ceiling	0.0034	0.0067	
Second	Shoe	Ceiling	0.0042	0.0056	
Second	Shoe	Gray boxes on shelves	0.0038	0.0086	

that immediately over a test station selected for the illumination

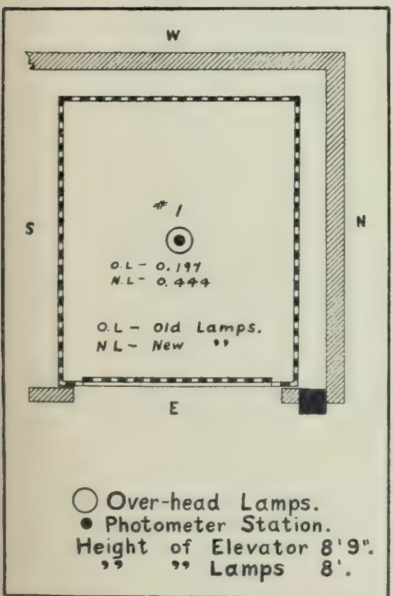


Fig. 56.—Section plan showing elevator No. 41 with location of lighting units, test stations and illumination data.

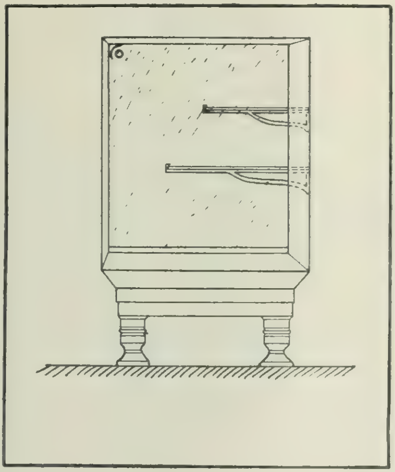


Fig. 57.—Plan showing end view of cases.

tests. In the shoe department, in addition to measurements of the brightness of the ceiling, measurements were made of the specific intensity of gray shoe boxes on the shelves. These were viewed normally. The results of these tests appear in Table IX.

In addition to these measurements of specific intensity, similar determinations were made on the main floor. These appear in Table X, where the values of candle-power per square inch

TABLE X.—SPECIFIC INTENSITY—MAIN FLOOR.

Surface	Angle of View	C-p. Per Sq. In.
Ceiling	Vertical	0.013
Pillars	20 to 35 degrees above horizontal	0.010
Distant elevator doors and metal trimmings	Horizontal	0.0016
Merchandise displayed in cases	About 30 degrees below horizontal	0.0024 (without case lamps)
Merchandise displayed in cases	About 30 degrees below horizontal	0.0088 (With case lamps)
Aisle floor	Vertical	0.0051

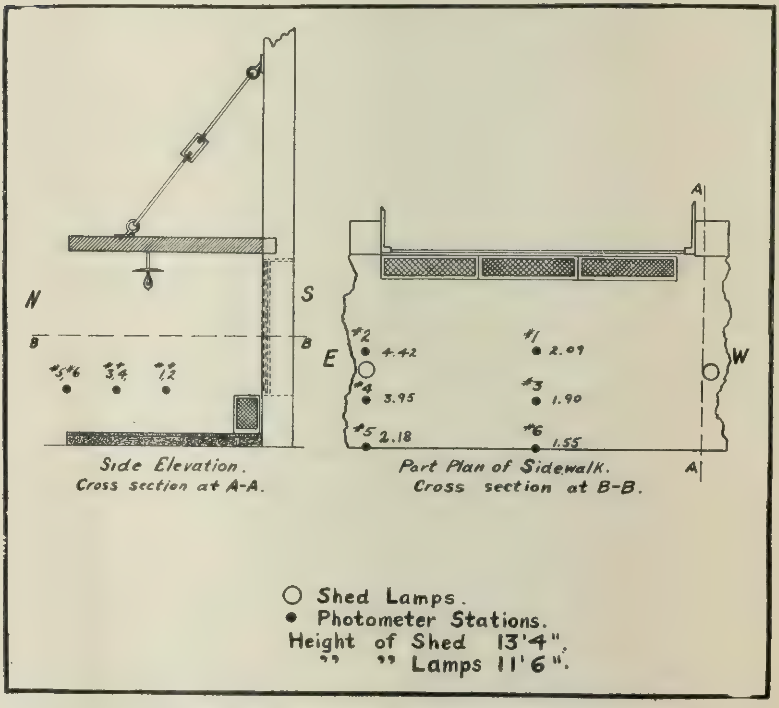


Fig. 58.—Showing plans and elevation of outside of shipping department.

are means of a few random measurements of the surfaces indicated.

As indicated in Table X, the ceiling and pillars of the main floor in particular and of other floors in general, are bright. On the main floor this is due first, to the fact that the finish

is of high light-reflecting power, and second, to the fact that in most cases the light sources diffuse the light rather generally and do but little in the way of directing it downward. The view of a shopper or employee, when not directed toward some article of merchandise, is likely to embrace a larger area of the bright ceiling and wall than of the darker finished cases, shelves and merchandise. This introduces a condition of glare which it was anticipated might have the three effects of reducing the ability to see, distracting the attention from merchandise and causing eye fatigue. The last factors too are difficult to determine and no efforts were made to investigate them. Tests were made to determine the effect upon visual power, and so far as they were carried out, indicated no very material deleterious

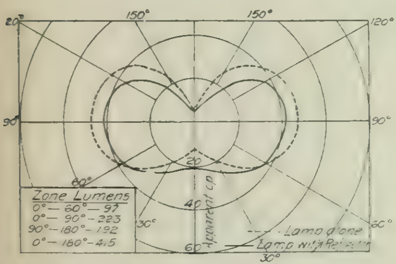


Fig. 59.—Photometric curve of 10-in. ground glass-ball with 60-watt bowl-frosted tungsten lamp.

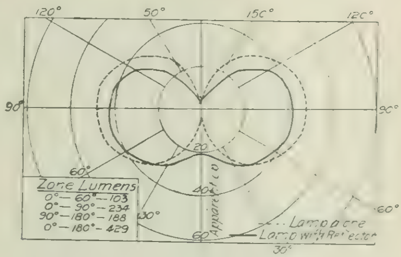


Fig. 60.—Photometric curve of 10-in. ground glass-ball with 60-watt clear bulb tungsten lamp.

effect. It is recognized that attempts at such determinations are likely to be involved in difficulty because of the many uncertain elements which enter into the problem; hence it is not asserted that there is no reduction in ability to see, due to the glare from the bright ceiling and pillars. It is merely stated that efforts to detect and measure such effect were unsuccessful.

The authors have yet to investigate certain experimental equipment designed with a view of eliminating undesirable effects, as, for instance, the large brightly illuminated white areas of ceilings and pillars. They had hoped to have incorporated some of their findings on the visualizing efficiency of the installation in this paper, but as the experimental work involved not only photometry and illuminometry, but a study of the physio-

logical and psychological phases as well, the work has assumed such proportions that they have been unable to satisfy their

Fig. 61.—Exterior view of the store showing Christmas lighting.

desires at this time. It is hoped that, in a subsequent paper, this very important phase of lighting, as related to stores, will be treated.

The authors take this means of heartily thanking, for their

greatly appreciated co-operation which has been of material assistance in the formation of this work, Messrs. Gimbel Brothers, the New York Edison Company and the Electrical Testing Laboratories.

DISCUSSION.

Mr. P. S. Millar:—The paper is essentially a description of the lighting installation of the Gimbel store, and a recounting of tests made of the lighting as it stands. So definite and specific is the description that there was needed only the opportunity which was afforded to observe the lighting effects to make it complete. Any description of this character must deal largely with facts rather than with opinions. That being the case, the paper does not provoke the spontaneous criticism and discussion that takes place when the papers deal almost exclusively with matters of opinion. With a perspicacity which is at the same time commendable and regrettable, the authors have very carefully refrained from expressing opinion of the lighting effects which have been obtained in the building.

This is one of the few well lighted department stores in this country. The quantity of light is ample, perhaps in some cases excessive. The quality of the light is as good, probably, as could have been obtained, when one is committed to the policy of using only one type of illuminant in the store. It is at this point that I hesitated in reading the paper. The requirements of lighting in a department store are so diversified that it would appear desirable to utilize several of the many different kinds of electric illuminants which are available.

The authors of the paper have pointed out that at least one room in the store should be equipped to furnish an equivalent of daylight. It seems to me we may go further and say that a number of rooms in a department store should have available such lighting effects. They should be equipped with alternative lighting systems, so that one may duplicate either daylight, or average artificial light. Many of the goods purchased in a store must be used in the daytime as well as in the night time—hence the desirability of such an arrangement.

In the paper it is stated that the ceiling and pillars of the

main floor in particular and of other floors in general are bright. "On the main floor this is due first, to the fact that the finish is of high light-reflecting power, and second, to the fact that in most cases the light sources diffuse the light rather generally and do but little in the way of directing it downward. The view of a shopper or employe, when not directed towards some article of merchandise, is likely to embrace a larger area of the bright ceiling and wall than of the darker finished cases, shelves and merchandise. This introduces a condition of glare which it was anticipated might have the three effects of reducing the ability to see, distracting the attention from merchandise and causing eye fatigue."

That seems to me to be the important point in connection with the lighting of this store, which should be considered carefully. Sometimes in a theatre, particularly a vaudeville theatre, in order to permit a quick transformation to be made on the stage without lowering the curtain, some lamps around the front of the stage, with reflectors behind them, are lighted, and the glare from these lamps is thrown into the eyes of the persons in the audience. The effect is that the stage seems to be in darkness. That is the most extreme condition of glare which one is likely to experience anywhere.

Whether or not a lighting system is successful, depends on the object for which it is installed. That is, the installation of lamps along the front of the stage in a theatre for the purpose of blinding the audience, is successful, because that is what it is put there for, but as a general system of lighting it is execrable. Whether or not the lighting of the first floor of the Gimbel store is successful depends on the object for which it was installed. If it was installed for the purpose of giving the effect of a brilliantly-lighted room, it is successful. If the lighting system was installed with the view of bringing out the beauties of the articles to be displayed, and revealing the details of these articles, attracting the attention of purchasers as much as possible to the merchandise, then in my opinion it is not successful, and needs modification.

Mr. J. S. Codman:—Generally speaking, it seems to me that the lighting of the store is extremely good, but I am inclined to

agree with Mr. Millar that in some cases the lighting is excessive.

There is rather more glare in the installation than is desirable. I do not feel sure by any means that it is on account of the light reflected from the ceiling. For example, in the auditorium, the ceiling does not seem to be bright, but the impression, upon entering the store from the street, was decidedly one of glare, and I think that this is principally due to the fact that the globes used are not good diffusers; that is to say, the light is seen through the globes in the form of spots and these spots are too intense and too brilliant for the eyes.

Mr. S. W. Ashe:—In connection with the table of dust measurements what time interval elapsed for the collection of the dust before the measurements were made?

Mr. Norman Macbeth:—Can the authors give any data showing the relative efficiencies of individual reflector and trough reflector used in window lighting?

Corrections were made in the tested illumination values for changes in voltage, the measurements throughout the building being corrected to the nominal light output for 120 volts. Were the actual illumination values as found throughout the building in the various departments greater or less than shown in this paper due to these corrections? The correction is, of course, for the purpose of bringing the intensities to standard conditions, but it is also very desirable to have this additional information as to the actual conditions.

I agree with Mr. Millar that when passing opinion on the lighting of the first floor one should know the purpose of the designers. The first time I saw the installation I was struck with the glare effect from the apparently numberless light sources, the result being far from satisfactory; the impression was that something was compelling attention to the ceiling, and only by special effort could I keep my eyes down to the counter plane. Other observers have stated that they experienced the same feeling.

Mr. H. T. Owens:—There is no doubt that the glare on the main floor is quite impressive to visitors who come into the store for the first time, although the type of lighting used is not one to show off the goods to the best advantage. The glare is not due to the quantity of light but rather to the type of glassware

and the color of the walls and ceiling. The use of diffusing globes and softer colors on the wall would materially improve the installation.

Mr. G. H. Stickney:—In one point at least my experience differs from the data given by the authors in Table I relating to the percentage of light absorption for different glassware. I believe that the minimum values are a little high and that for ground glass 15 per cent. would be nearer right than 20 per cent., for alabaster 10 per cent. instead of 20 per cent. and for opal glass the minimum should be about 12 per cent.

The lighting in general seems to be a departure from the usual New York practice and to tend more toward that followed in certain western stores where a large number of small units are employed.

Unquestionably the high-efficiency metallic-filament lamp is the most satisfactory illuminant available for the upper floors of a dry-goods or department store. As to the main floor of such a store, the issue is not quite so clear. In some cases the metallic-filament lamp may be preferred and in others the intensified arc. This I believe depends to some extent upon the purpose of the lighting, as suggested in Mr. Millar's discussion. In a demonstration which I conducted in a large western store within the past year the metallic-filament lamp was selected because of the pleasant general effect in the store. However, there was considerable hesitation, as it was considered that the arc lamps showed the color of the merchandise more accurately. The decision was not unanimous and there is considerable question in my mind which of the two illuminants will give the greater satisfaction.

Mr. V. R. Lansingh:—Relative to the use of different colored illuminants, I want to call attention to one rather particular case of lighting, namely, in the jewelry department, especially where diamonds are to be shown. The higher priced and higher value diamonds are those with the color of blue, the yellow diamond being the least valuable. Consequently, in order to show diamonds to the best advantage, it is desirable to show them under blue light. For this service nothing has been devised which gives better effect than the arc lamp, its light being unfiltered by any colored globe whatever. In a large jewelry store in Salt

Lake City, this is taken advantage of, and the clear arc lamp, with a prismatic globe simply to break up the light, is used for this purpose, the result being very satisfactory.

Mr. Marshall:—In reply to Mr. Millar, I wish to state that the lighting of the first three floors in general, and the first floor in particular, was designed by the architects to be attractive in appearance first, and efficient, in so far as illumination results were concerned, in the sceond place.

I have spoken so many times about my dislike for ground glass that I did not make mention of this lack of appreciation in this paper. Ground glass in the form of spheres is not a particularly good diffusing or a redirecting medium. When an illuminant is placed inside of a sphere, say 10 ins. in diameter, the sphere appears to be of such dimensions only when unlighted; however, when the illuminant is lighted, the sphere, to the eye, is reduced in size almost to the spot of light noticeable in the center of the sphere. Such condition is not only not artistic, but inasmuch as the light flux is not diffused to any great extent the use of such glassware is not to be considered where low intrinsic brilliancy of light sources is desired. Where two or more lamps are used inside of such a sphere, the effect becomes almost grotesque, because instead of having a symmetrical unit, there is one in which the several points of light are most conspicuous, the symmetry of the ball being absolutely destroyed. Milk (opal) glass is far preferable for spheres to ground glass, even though the absorption is higher, for with these is obtained a fullness, due to perfect diffusion, that is wonderfully beautiful and a low intrinsic brilliancy of surface that is desirable. Either plain milk balls de-polished on the exterior, or straw, opalescent balls, similarly treated on the exterior, produce a very pleasing effect.

Concerning the dust question; as the paper indicated, the results were not the product of very extended tests. One reading was taken at each of the several test stations in the store. These tests were made approximately five months after the equipment had been installed. Attention should be called to the fact that in the paper certain depreciation values were given for the lamps, and in justice to the lamps, it should be stated that these values are open to question, because the lamps had not all been in use

for the same length of time; they had been installed from time to time since the date of the first installation.

As regards the efficiency of a light source individually equipped with a reflector so constructed as to redirect the light rays in certain directions, versus the so-called trough reflector, where the lamps are placed in such a manner that the redirection becomes general, I do not consider it proper here to go into the discussion of such a matter, because of the commercial element that would probably be introduced, but I can say that a study of show windows lighted with these two forms of reflectors will prove conclusively that the individual reflector is more efficient than the old style trough reflector. It is interesting to note that those people who heretofore have manufactured trough reflectors, are now constructing individual reflectors.

The voltage in the building is remarkably steady; as stated in the paper, there is a substation in the basement operated by the New York Edison Company.

As to bowl-frosted lamps, it so happened that frosted-tip lamps were delivered at the building, the manufacturers of such lamps understanding that they would be employed in the open reflectors. As sufficient time was not available to make additional shipment, these lamps were used. When the frosted-tip lamps burn out in the balls clear lamps will be used; in the reflectors, the frosted-tip lamps, of course, will be employed.

The authors have endeavored to ascertain the undesirable effect of light ceilings, and pillars, on the eye, but so far as they have been able to carry out the experiments, no tangible results have been obtained. However, it is believed that if this large expanse of white brightness be eliminated the eye will be enabled to "see" very much more easily.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VI. APRIL, 1911. NO. 4

COUNCIL NOTES.

A meeting of the council was held in the general office April 14th. Those in attendance were A. E. Kennelly, president; V. R. Lansingh, treasurer; L. B. Marks, chairman finance committee: Preston S. Millar, general secretary: A. S. McAllister, G. S. Barrows, George Ross Green, W. H. Gartley, and Bassett Jones, Jr., chairman of papers committee.

After the receipt of the usual monthly reports of the secretary and the chairman of the finance committee, a report from the committee on section development was discussed at length. The report contained several proposed changes pertinent to the organization and policies of the sections. It was accompanied by a supplementary report which included suggestions concerning an enlargement of the work of the Society. In the supplementary report were also incorporated a number of communications from members recommending new lines of work. The discussion of the recommendations contained in both reports resulted in the appointment of a committee on policy. This committee will serve until the end of the year and will not only take up the recommendations of the committee on section development but will consider other questions involving the society's policy and development. The personnel of the committee is as follows: President A. E. Kennelly, chairman: Past Presidents L. B. Marks, C. H. Sharp, Louis Bell, W. H. Gartley, E. P. Hyde: V. R. Lansingh, treasurer: and Preston S. Millar, general secretary. It is expected that a report from the committee will be forthcoming before the June council meeting.

A resolution was passed modifying the publication policy of the society. Hereafter the technical press will be permitted to abstract any paper before it is presented at a section meeting, or to reprint it in full after it is thus presented. Heretofore

the rules of publication did not permit such reprinting or abstraction of a paper before it appeared in the Transactions.

The general secretary reported upon certain correspondence with the chairman of the committee on hygiene of the eyes of the section of ophthalmology of the American Medical Society. The members who have been invited to attend a meeting of that committee were authorized to signify the willingness of the Illuminating Engineering Society to appoint a committee to undertake coöperative work.

A committee was appointed to consider the advisability of establishing a section in Washington, D. C.

Twenty-six applicants were elected to membership.

SECTION MEETINGS.

CHICAGO SECTION.

A meeting of the Chicago Section was held in the Green Room of the Kuntz-Remmler Restaurant, Chicago, at noon April 20th. Charles R. Gilman, of Milwaukee, Wis., chief electrician of the Chicago, Milwaukee and St. Paul Railway Company, read a paper on "Recent Developments in Train and Car Lighting." Discussion was offered by Messrs. Albert Scheible, C. W. Naylor, T. H. Aldrich, M. G. Lloyd, F. A. Vaughn, G. C. Keech, A. J. Sweet, A. M. Wilson and C. R. Gilman.

At the meeting to be held on the evening of May 18th, Mr. Charles A. Luther, illuminating engineer of the Peoples Gas Light & Coke Company, will present a paper on the "Illumination of the Peoples Gas Building." This meeting will probably be held in that building.

At the June meeting Mr. W. D. Bradley, of the American Luxfer Prism Company, will read a paper on "Natural Daylight Illumination." This will complete the present season.

NEW ENGLAND SECTION.

The New England section held a meeting Monday, April 10th. A paper on "Modern Gas Illumination" was read by Mr. T. J. Litle, Jr.

At the meeting to be held Monday, May 8th, Mr. W. E.

Wickenden, assistant professor of electrical engineering in the Massachusetts Institute of Technology, will present a paper.

NEW YORK SECTION.

At the April meeting of the New York section held in the United Engineering Societies' Building three papers were presented. The first paper, "The Photometry of Mercury-Vapor Lamps," was read by Dr. Joseph C. Pole. This was followed by a paper entitled, "Polar Curves of Finite Line and Surface Light Sources," by Mr. Bassett Jones, Jr., and a paper on "Sign Lighting" by Mr. O. P. Anderson. Mr. Anderson's paper was supplemented by a number of stereopticon views of various electric sign installations. All three papers with the attending discussion appear elsewhere in this issue.

At the next meeting, which will be held May 11th in the United Engineering Societies' Building, Prof. R. S. Woodworth of Columbia University, will present a paper on the "Psychology of Light."

PHILADELPHIA SECTION.

A meeting of the Philadelphia section was held Friday, April 21st. Mr. E. C. Crittenden, of the Bureau of Standards read a paper entitled, "An Experimental Study of Flame Standards."

The next monthly meeting will be held Friday, May 19th. Mr. W. D' A. Ryan of the General Electric Company will read a paper entitled, "Mill Lighting." The paper will be supplemented by a series of lantern slides.

OBITUARY.

DR. HENRY GRADLE.

As this issue of the TRANSACTIONS goes to press word is received of the death of Dr. Henry Gradle at Santa Barbara, Cal., April 4th. Dr. Gradle was one of the foremost ophthalmologists in Chicago. He had been affiliated with the Chicago section for several years and had manifested a keen interest in the affairs of the Society.

A STUDY OF THE ENERGY LOSSES IN ELECTRIC INCANDESCENT LAMPS.[1]

BY EDWARD P. HYDE, F. E. CADY AND A. G. WORTHING.

I. INTRODUCTION.

In studying the radiating properties of matter it is frequently convenient, especially in the case of metals, to mount the material to be investigated in the form of a filament in an exhausted bulb, as in the ordinary incandescent electric lamp. This arrangement is particularly advantageous if the relation between the supplied power and the radiated power is known, since it is then possible to determine the radiation at any temperature, *i.e.*, at any voltage, by measuring the power supplied to the lamp.

The possible difference between the power in-put and that radiated by the filament will depend in general upon three factors: (1) the C^2R loss in the leading-in wires and joints; (2) the fraction of the supplied power that is dissipated by convection and conduction of heat by the gas enclosed in the bulb; and (3) the fraction dissipated by thermal conduction along the leading-in and supporting wires. There is no reason why the C^2R loss may not be made as small as desired. In ordinary commercial lamps it is less than 1 per cent.,—more usually of the order of magnitude of 0.1 per cent. or 0.2 per cent. In cases where it may be necessary, it is possible to correct for this loss.

Although the loss by gas conduction and convection is quite large if the bulb is not well exhausted, amounting in extreme cases to several hundred per cent., it is negligibly small when the vacuum is of the order of magnitude of 0.001 or 0.002 mm. of mercury, or less. The relation between the pressure of air in the bulb and the power required to maintain a filament temperature of approximately 1,400° C. is shown in Fig. 1, for the case of a platinum filament 15 cm. long, and 0.1 mm. diameter, mounted in a pear-shaped bulb of 8 cm. maximum diameter and 13 cm. length. The magnitude of this loss will depend, of course, upon the size of the bulb, the nature of the enclosed

[1] A paper presented at a meeting of the New England Section of the Illuminating Engineering Society, February 13, 1911.

gas, the size and material of the filament, and the temperature of operation. The higher the temperature, the smaller is the relative loss. Platinum, because of its low emissivity, undoubtedly gives a larger loss than some such substance as base-carbon. Hydrogen would carry away relatively more of the supplied power than air at the same pressure. But in all ordinary cases, as in commercial lamps, the conditions are such that the loss due to the conduction and convection by the enclosed gas is negligibly small.

With regard to the losses by conduction away of the energy

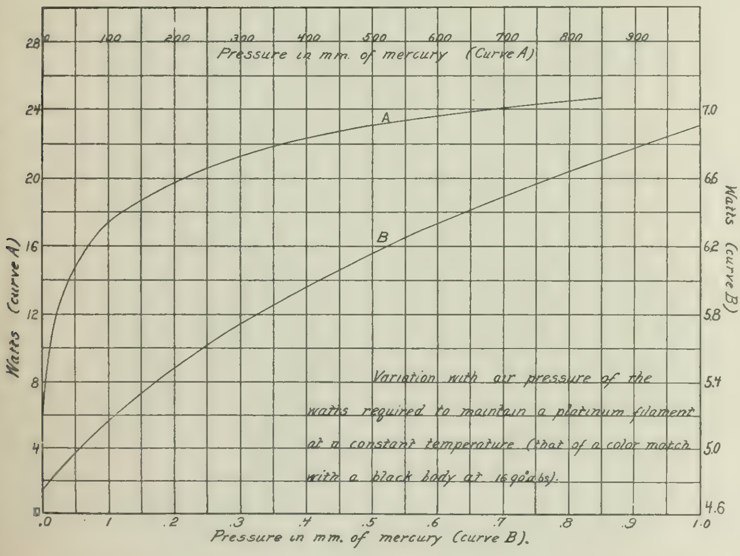


Fig. 1.

of the filament by the leading-in and supporting wires, there has been much discussion. In a previous investigation[1] by one of the authors et al. of the selectivity in the radiation of certain metals, it was assumed that this loss by conduction away of heat is small,—at least, that the relative difference in this loss for two different lamps, or for the same lamp at two different temperatures is negligible. This assumption was based partly on a casual inspection of the filaments when incandescent and partly on the experience of lamp makers who find

[1] *Elec. World*, 53, p. 439, 1909. TRANS. Ill. Eng. Soc., 4, p. 334, 1909. *Jour. Frank. Inst.*, 169, p. 439, 1910.

that practically the same data may be used in computing the dimensions of lamps of different voltages and wattages within reasonable limits.

The same assumption has been made by Drysdale[2] and Fery[3]. On the other hand direct measurements by Helmholtz[4], Lux[5] and Leimbach[6] of the total radiation have indicated large differences between the power supplied to the lamp and that radiated by it. The results of Leimbach whose work is the most recent and most complete on the subject will serve as an illustration. He finds for the "relative radiating power" (ratio of radiated to supplied power) of the various carbon and metal-filament lamps values ranging from 61.9 per cent. to 80.5 per cent. Thus in the most favorable case approximately 20 per cent. of the supplied power is not radiated to the measuring bolometer, and on the average the loss amounts to about 30 per cent. Moreover, it would seem that this loss is ascribed principally, though not entirely, to the heat conduction at the leading-in and supporting wires. At least, differences of 15 per cent. (as between the A. E. G. 228-volt tungsten and the "Sirius"-Kolloid 220-volt tungsten lamp) are ascribed to differences in supports which would seem to indicate that the total loss in every case is due primarily to heat conduction at the leading-in and supporting wires.

2. GENERAL METHOD.

The discrepancy between the large losses found by direct experiment, and the relatively small ones which general considerations and the experience of manufacturers would indicate, suggested the importance of further investigation of the subject, particularly as the present authors' conclusions regarding selectivity in the radiation of various substances rest on the assumption that the ratio of luminous flux to total power radiated in the case of an ordinary incandescent lamp is approximately equal to the lumens per supplied watt, *i.e.*, that the losses by thermal conduction are comparatively small.

In approaching the problem it is well to discriminate between

[2] *Jour. de Phys.*, (4) 7, p 872, 1908. *Lond. Ill. Eng.*, 1, p. 642, 1908.
[3] *Bul Soc. Int. des Elec.*, (2) 9, p. 673, 1909.
[4] *Beiblaetter*, 14, p. 589, 1890.
[5] *Lond. Ill. Eng.*, 1, p. 98, 1908.
[6] *Zs. f. wiss. Phot.*, 8, p. 333, 1910.

the energy radiated by the filament and the energy radiated by the lamp as a whole. These two quantities of radiation may differ, and the quality of the radiation from the filament may be different from that from the lamp as a whole. The glass bulb absorbs some energy of every wave-length, but the absorption in the visible spectrum is quite small. Beyond 2.5 μ in the infra-red, glass begins to exhibit strong absorption. The energy absorbed by the glass is dissipated again, partly by radiation of very long wave-lengths and partly by conduction and convection by the air. Moreover, in the case of old lamps there is a deposit formed on the inner side of the bulb, and this deposit absorbs strongly in the visible, as well as in the infra-red region of the spectrum. Drysdale[7] by a calorimetric method measured the energy lost by convection from the bulb in a particular lamp and found the loss to be of the order of magnitude of 2 or 3 per cent.

Some few observations were made on the absorption in the visible spectrum of lamp bulbs, including both new bulbs and those on which there was a marked deposit. In the case of new lamps the decrease in luminous flux owing to absorption by the bulb amounts to only 2 or 3 per cent. Bulbs of lamps which had burned to approximately one-quarter of their normal lives, showed absorptions of the order of magnitude of 5 per cent. or 6 per cent., differing of course from lamp to lamp. Very old lamps which had burned out were so darkened with deposit that absorptions as large as 25 per cent. were observed. It is evident, therefore, that for lamps which have been seasoned, but not burned to any great extent, the absorption of visible radiation need not exceed 5 per cent., and that the relative differences between lamps of different types should be much smaller than 5 per cent.

In the methods employed by Helmholtz, Lux and Leimbach, the total radiation from the lamp was measured, but since the large observed differences between the power supplied and that radiated were attributed by Leimbach to a great extent to the thermal conduction losses at the supports, it seemed advisable to apply some new method which would give the difference between the power supplied to the *filament* and that radiated by the

[7] *Loc. cit.*

filament. This difference would unquestionably be due only to thermal conduction losses. In the case of moderately new lamps, in which there is no marked deposit on the bulb, this difference gives more nearly the real error which results from the assumption that the lumens per applied watt is the same as the lumens per watt radiated by the filament. It is therefore the more significant error in the methods employed by one of the authors et al. in the study of the radiating properties of metals.

The method employed in the present investigation consists, in brief, in determining the power supplied to every millimeter length of filament, the power radiated by every element of filament, and the luminous value of the radiation from every element of filament. These data give at once the difference between the power supplied and that radiated by the whole filament, and hence the loss by thermal conduction. The data also give the difference between the actual efficiency of the filament, and the efficiency it would have if there were no conduction losses.

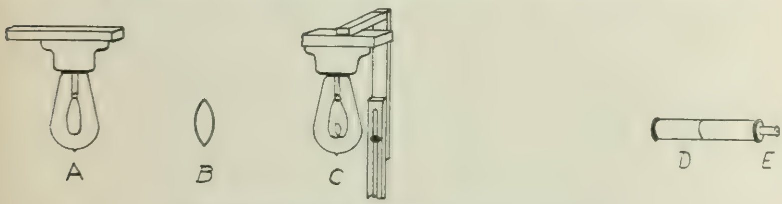
The casual inspection of a lamp in operation, particularly of a metal-filament lamp, shows the cooling effect of the leading-in and supporting wires. It is quite easy to measure the supplied power, the radiated power, and the luminous flux of a unit length of filament at any point, without making any temperature measurements or any assumptions whatever regarding the temperature. The method employed, which is an application of the principle of the Holborn-Kurlbaum optical pyrometer, is as follows:

An image of a part of the filament of a large-filament lamp A (Fig. 2) is projected on an enlarged scale by means of the lens B on the plane of the filament of the lamp C under investigation. The telescope D is focussed on the filament of lamp C so that the filament of C is seen in the telescope against a bright background consisting of the enlarged image of the filament A which is also in the focus of telescope D. By varying the current in the auxiliary lamp A the filament of C can be made to disappear against the background. The disappearance can be secured more accurately if monochromatic light is

used, and to this end a strip of red glass is placed over the eye-piece E of the telescope.

The test lamp C is mounted on an adjustable support. By raising or lowering lamp C, different parts of its filament can be seen against the bright image of filament A, as a background. As successive portions of the filament of lamp C are seen against the image of A, the currents in A corresponding to a disappearance are determined. In this way the whole filament is explored, measurements being made as close to the leading-in and anchoring wires as the reduced luminosity of those cooled portions will permit.

The results for one of four filaments of a 110-volt, 60-watt tungsten lamp, taken as an illustration, are plotted in Fig. 3, curve "A." The abscissas are distances along the filament from a leading-in wire to successive points on the filament up to the



Diagrammatic Sketch of Apparatus.

Fig. 2.

end of the filament where it is welded to a support at the base-end of the mount. The ordinates are the values of the current in the background corresponding to a disappearance of the various portions of the test filament, as seen in the telescope. The filament was 160 mm. long, and intermediate between the two ends, at 80 mm. from the leading-in wire, the effect of an anchoring wire of the ordinary loop form is seen.[5] Near the leading-in wire the filament is cooled by thermal conduction, and so the emission is decreased. It is therefore necessary to reduce the current in the background lamp in order that the two may have the same apparent emission, *i.e.*, in order that there may be a disappearance as seen in red light through the telescope. In the neighborhood of the anchoring wire the cool-

[5] In Fig. 3, as in the following figures, it should be kept in mind that a considerable portion of each curve corresponding to the portion of the filament glowing with maximum brightness has been omitted.

ing effect is again noticed, though the magnitude of the cooling here is not as great as at the leading-in or other welded joints. In fact it is frequently difficult to measure the cooling effect at the loose anchors because the contact between the filament and the anchor is variable; at one moment there is apparently no cooling whatever, and a moment later a fairly good contact is established. By taking all four of the filaments between successive welded joints in a tungsten lamp an average result is obtained. In the tantalum lamp there are only

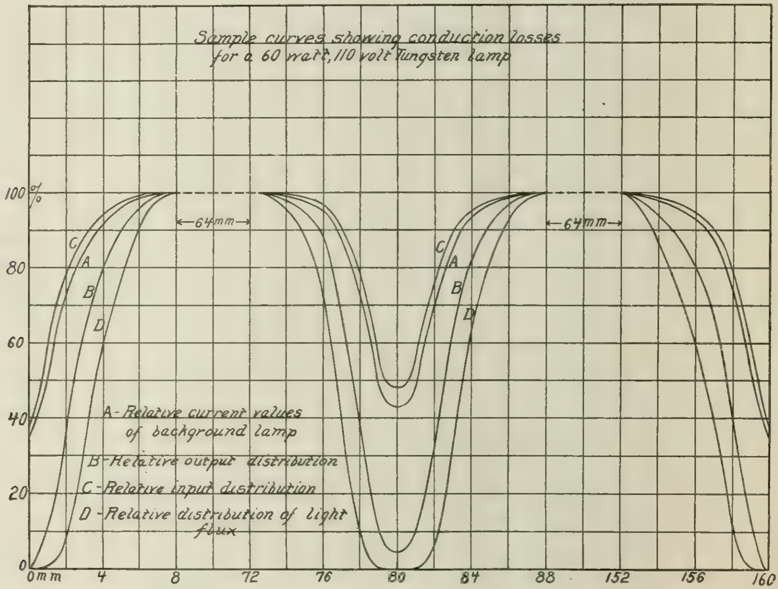


Fig. 3.

two rigid joints, at the leading-in wires and 21 loose anchors. By taking a large number of the anchors, however, it is possible to average up with fair accuracy the uncertainty due to the variable contacts.

Data similar to those represented in Fig. 3, curve "A," for one filament of a 25-watt tungsten lamp were obtained for a number of lamps of different types. In every case, when the lamp was operating at normal voltage the cooling effect was found to extend only a short distance from the contact points as exhibited by the flatness of the current curve throughout

the greater part of its length. This fact that the cooling effect is confined to the parts of the filament quite near the supports renders available a simple method of determining with a fairly high accuracy from the observed curve of background current, as in Fig. 3, curve "A," the losses in watts and in efficiency due to the conduction away of heat at the supports.

The exact significance of the background current corresponding to a disappearance of the test filament against the background is of interest in passing. If there was no absorption of red light in the passage of the radiation from the filament of lamp A (Fig. 2) through the bulb of A, or through the lens system B, or through the bulb of lamp C, the intrinsic brightness of the enlarged image of filament A in the plane of filament C would be the same as the intrinsic brightness of the filament A itself. If these conditions held, then when the current of lamp A was adjusted so that the test filament C disappeared against the background image of filament A, the two filaments would have exactly the same emission in red. If both filaments were of the same material, *e.g.*, tungsten, which is the material of the background lamp, and if the surfaces of the two filaments were the same, the two filaments would be at the same temperature and hence of the same color. Owing, however, to absorption of light in the passage of the radiation from filament A to its image in the plane of C, it is necessary to operate lamp A at a higher temperature than would otherwise be necessary; and so the color of the light from A is much whiter than that from a tungsten test lamp C when at a disappearance as seen in the telescope.

It is not necessary, however, to introduce any of the properties of lamp A into the determination of the conduction losses of lamp C. Lamp A is used only as a comparison lamp, and is entirely eliminated by a substitution method. The applicability of this method rests on the fact, pointed out above, that the cooling effect for the lamp being studied is relatively small, and is confined to the parts of the filament quite close to the supports. Under these circumstances, if the test filament C is operated at two different voltages, the ratio of the total emission at the two voltages of a millimeter length of filament taken near the center of the filament, *i.e.*, away from the supports, is

the same, to within second order differences, as the ratio of the power supplied to the lamp as a whole at the two voltages. This relation furnishes a method of interpreting the observed values of background current in terms of watts radiated by different portions of the test filament. Thus, after having explored the entire filament of lamp C, by moving it up and down, and determining the background current for disappearance at each of a number of points along the filament, some part of the filament away from a support is brought again into the field of the telescope so that it is seen against the background image. The voltage of the test lamp, which was maintained constant during the previous test, is now varied, and the background current is adjusted so that there is a disappearance, *i.e.*, so that the test filament C and the image of A are at the same apparent brightness. By varying the voltage of the test lamp C over a large range, making background current determinations at frequent intervals and measuring the watts of the test lamp at each voltage, a calibration curve is obtained between the current in the background and the watts supplied to the test lamp, which latter may be taken as proportional to the watts radiated by the element of filament of the test lamp under investigation. Such a calibration curve for the tungsten lamp to which Fig. 3, curve "A," applies is shown in Fig. 4, curve "A." If now for the background current readings in Fig. 3, curve "A" the corresponding watts of the test lamp are plotted, the resulting curve (curve "B," Fig. 3) plotted in terms of an arbitrary unit, will give the relative energy radiated by every element of filament of the test lamp C at the fixed normal voltage of the lamp. The integral of this curve will give the total power radiated by the filament, expressed in the same arbitrary unit.

Now, since the energy supplied to an element of filament near the center, *i.e.*, away from the supports, is all radiated, there being no conduction loss, the curve of power supply for this portion will coincide with that of power radiated, if plotted to the same scale. As the leading-in and supporting wires are approached, however, the two curves will diverge. If the resistance of every element of filament were the same, the curve of energy supply would be a straight line parallel to the axis of abscissas. On account of the cooling at the contact points,

however, the resistance of unit lengths of filament near the contact points, will differ from that of a unit length in the central region of the filament, and hence the power supplied to these elements near the contacts will be different from that supplied to the central portion, being directly proportional to the resistance.

The resistance of every element of filament can be determined in a way quite similar to that employed in the determination of the radiation from each element. Fig. 4, curve

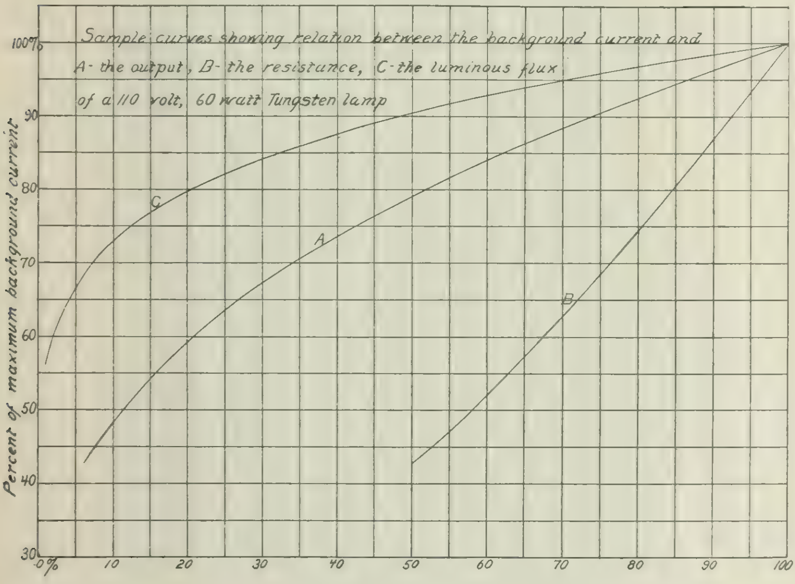


Fig. 4.

"B," gives the resistance of the entire filament of the tungsten test lamp (expressed in an arbitrary unit) plotted against the background current values which give a disappearance for a central portion of the filament at varying voltages. The ratio of the resistances of the whole lamp at two voltages may be considered to within second order differences as equal to the corresponding ratio of the resistances of a unit length of filament near the center. Hence from curve "B," Fig. 4, may be read the resistance of any element of filament corresponding to a background current taken from curve "A," Fig. 3. If

the watts supplied to an element of filament near the center be taken as unity, then the power supplied to any element of filament near the contacts will be that fraction of the power supplied to a central element which the resistance of the end element is of the resistance of the central element. The power supplied to every element of the tungsten filament which has been taken as an example is given in Fig. 3, curve "C." The integral of this curve gives the total power supplied to the filament, and the ratio of the integral of curve "B" (the total power radiated) to the integral of curve "C" (the total power supplied), gives the proportion of the supplied power which is radiated. The difference between this ratio and unity gives the percentage of power lost by thermal conduction. In the case of the tungsten filament in the illustration it amounts to 4 per cent.

From an inspection of Fig. 3 it is seen that curve "B" giving the radiated power, is extrapolated to zero at the contact points, whereas curve "C" is given finite values at these points. Unquestionably the filament has a temperature above that of the surrounding medium even at the contacts, and so curve "B" should have finite values at these points; but in order that the maximum loss might be determined it seemed advisable, in the absence of specific knowledge of the true values at these points, to assume the worst case by extrapolating to zero.

Having determined the power supplied and the power radiated for every element of filament, it only remains to measure the luminous flux for every element of filament, and thus to determine the loss in efficiency due to the losses of energy by thermal conduction. The method pursued in determining the luminous flux of each element of filament is entirely analogous to that used in getting the power supplied and the power radiated by each element. Thus, Fig. 4, curve "C," gives the relation between the luminous flux of the whole lamp and the background current corresponding to a central portion of the test filament at different voltages. From this curve, in conjunction with curve "A," Fig. 3, it is a simple matter to compute the curve of luminous flux, as shown in curve "D," Fig. 3, plotted in terms of an arbitrary unit. The integral of this curve gives the total luminous flux of the whole filament, and the ratio of this integral

(the total luminous flux) to the integral of curve "C" (the total power supplied) gives the efficiency in terms of the efficiency at the center of the filament taken as unity. The difference between this ratio and unity gives, therefore, the percentage loss in efficiency due to the losses by thermal conduction. In the case of the tungsten filament which is taken as an example, this loss amounts to 7 per cent.

3. EXPERIMENTAL RESULTS.

The method described fully in the preceding section may be summarized briefly. (1) The current values of the background lamp corresponding to a disappearance of the various parts of the test filament at constant voltage are determined. Then for some central portion of the test filament the following three relations are determined by varying the voltage of the test lamp and recording the corresponding background current; (2) background current versus foreground watts; (3) background current vs. foreground resistance; (4) background current vs. foreground luminous flux. By combining (2), (3) and (4) with (1), it is possible to obtain the power supplied, the power radiated, and the luminous flux for every element of length of the test filament.

In actually carrying out the investigation, the method given above was not followed rigorously. Thus, the background lamp was employed only in determining relations (1) and (2). For relations (3) and (4) were substituted the following, which in the light of relation (2) give all the necessary data: (3′) foreground watts vs. foreground resistance; (4′) foreground watts vs. foreground luminous flux.

In practice the method consisted in first determining relation (2) which may be considered a calibration of the background filament. Then relation (1) was determined, but the results were not reduced to a curve. The calibration of the filament—relation (2)—was then repeated, and the mean of the two calibrations plotted in the form of a curve. From this curve the watts value of every observed background current value in relation (1) was read-off, and the results plotted in the form of a curve, in which distances along the filament were taken

as abscissas, and watts radiated (in an arbitrary unit) as ordinates.

In getting relation (2) the test lamp was set at various voltages, and the background current for a disappearance was obtained; at the same time current readings of the test lamp were taken. From the latter the watts and resistance at each voltage were computed. In this way relation (3′) was obtained simultaneously with relation (2). To get relation (4′) the lamp was set up again since the experimental arrangement did not permit candle-power determinations to be made at the same time as the other measurements.

As a background lamp a large filament tungsten lamp was used. The filament was approximately 0.4 mm. in diameter, and was of an inverted U-shape, mounted in a large bulb. Several different lamps were used, in some cases the bulb was spherical, in others of the more usual pear-shaped form. In each case the filament was so mounted that the end of the loop came near the center of the bulb. This portion of the filament was in general chosen as the background for the measurements.

The investigation was carried out with the following four lamps, each at two different voltages: 16-c-p., 115-volt, 3.1 w.p.c. carbon lamp; 40-watt, 110-volt, tantalum lamp; 25-watt, 115-volt, tungsten lamp; and 60-watt, 110-volt, tungsten lamp. The losses were determined at voltages corresponding to approximately normal operation, and at very low voltages so chosen that all the lamps were at about the same color as the carbon lamp at 75 volts. Only one lamp of each type was used, as the observations and computations are quite laborious, and as it is felt that there is no reason why the losses should differ greatly from lamp to lamp of the same type and at the same efficiency.

The carbon lamp was of the anchored oval type, thus having two leading-in wires, and one anchor at the center of the oval. The tantalum lamp was of the continuous filament variety with two leading-in wires and twenty-one loop supports. The 25-watt tungsten lamp and similarly the 60-watt tungsten lamp had four filaments, each of which was welded at the base contacts and supported at the other end by a loop support. There were thus two leading-in wires, six other welded supports and

four loop supports. In the case of the carbon lamp, the filament was investigated in the region of each leading-in wire and of the one anchor. The effect of the two leading-in wires, and of ten of the twenty-one loop supports was studied in the tantalum lamp. In the 25-watt tungsten lamp the losses at the two leading-in wires, at three of the six other welded contacts, and at two of the four loop-contacts were determined. In the 60-watt tungsten lamp approximately the same number of contacts were studied.

The losses at the loop-contacts were the most difficult of

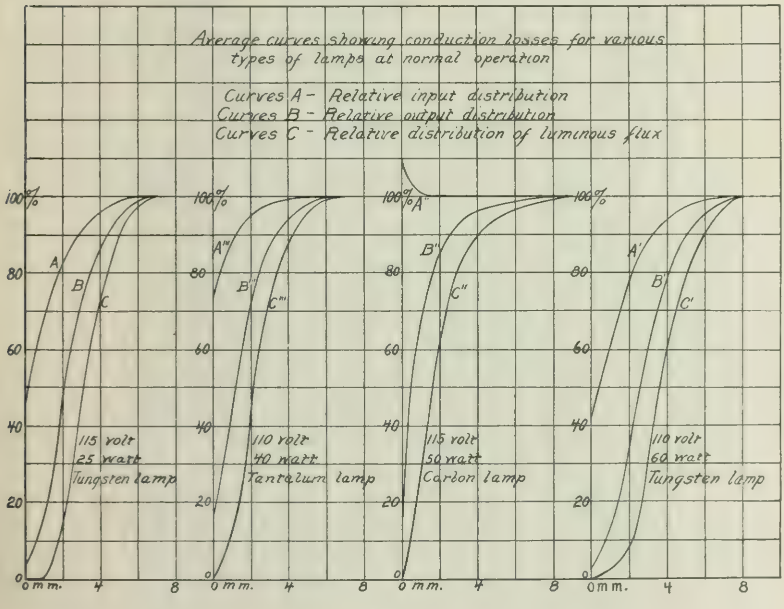


Fig. 5.

measurement because of their changing nature. By taking a relatively large number, however, a fairly accurate result was obtained.

The results of the investigation are given in Figs. 5 and 6, and in Table 1. In describing the general principle involved in the method, typical curves for a 60-watt tungsten lamp were given in Fig. 3, curves "A," "B," "C" and "D." In giving the final results it has seemed better to plot the average curves for

each lamp. Thus in Fig. 5, curve "A," the abscissas are the average distances from the contact points, and the ordinates are the average values of power supplied to the filaments at the corresponding distances from the contact points. The ordinates are expressed in terms of an arbitrary unit so chosen that the

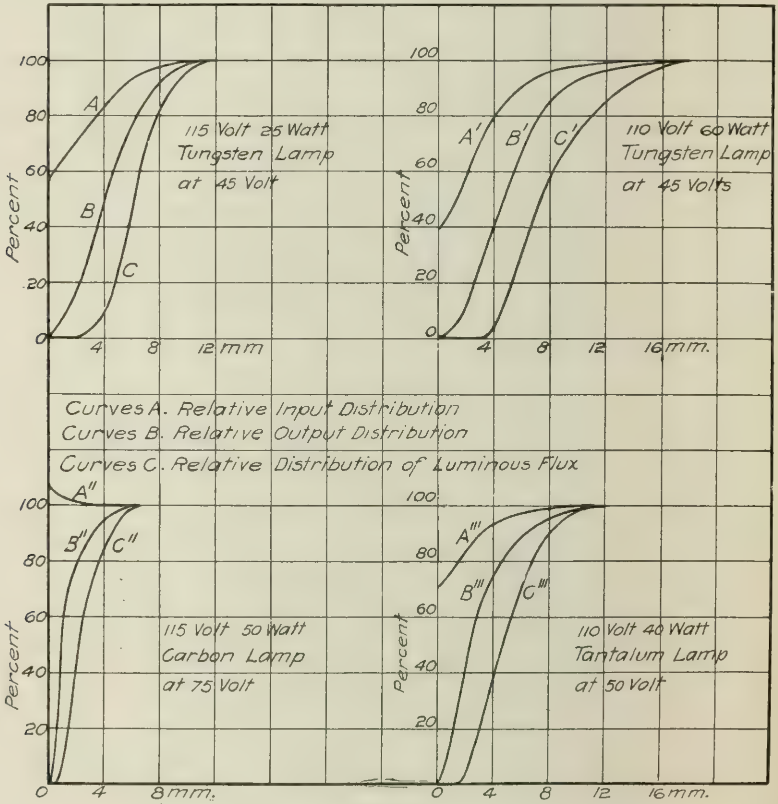


Fig. 6.—Average curves showing conduction losses for various types of lamps at reduced voltages.

value of the maximum power supplied per unit length of filament is unity. Curve "B" gives the average power radiated at various distances from the contact point; and curve "C" shows the average luminous flux per unit length of filament.

The area between curves "A" and "B," divided by the area enclosed under curve "A" *properly extended* gives the per-

TABLE I.—SUMMARY OF ENERGY AND LUMINOUS EFFICIENCY LOSSES IN VARIOUS TYPES OF LAMPS DUE TO THE CONDUCTION OF HEAT AWAY FROM THE FILAMENT AT THE LEADING-IN AND ANCHORING WIRES.

Lamp	Voltage	Watts / M. H. C.	Energy loss Per cent.	Efficiency loss Per cent.	Distance between successive contacts mm.
Tantalum No. 3	110	2.0	7	13	33
40-watt	50	11.0	14	27	..
Carbon No. 53	115	3.1	2	4	106
50-watt	75	18.0	3	5	..
Tungsten No. 45	115	1.25	4	7	69
25-watt	45	12.0	9	15	..
Tungsten No. 47	110	1.25	4	7	80
60-watt	45	11.0	8	16	..

centage loss in power due to thermal conduction at the contacts. The area between curves "A" and "C" divided by the area enclosed under curve "A" *properly extended* gives the percentage difference between the actual efficiency of the lamp, and the efficiency of the most efficient part of its filament, *i.e.*, the part of the filament away from the cooling effect of the contacts. The reason why the average efficiency of the lamp is lower than that of its most efficient part is to be found in the fact that the efficiency of those parts of the filament near the contact points is quite low. The amounts of the losses in power and the losses in efficiency for the various lamps are given in the respective figures and are collected in Table 1.

In the first column of Table 1 are given the various lamps used; in the second and third columns the voltages and the watts per mean horizontal candle at normal operation and at reduced voltages; in the fourth and fifth columns are given the percentage losses in watts and in efficiency at normal operation and at reduced voltages; and in the sixth column are given the lengths of filament between two successive points of support for the various lamps. It will be observed first that the power losses (fourth column) in the case of ordinary lamps at normal operation are relatively small, amounting only to about 7 per cent. even for the tantalum lamp, which shows the largest loss. As the voltage is decreased, the loss becomes relatively larger for every lamp; but even at the very low voltages used and for the worst case of 14 per cent. loss in the tanta-

lum lamp operating at 11 watts per mean horizontal candle, the power losses are still considerably less than the values given by Leimbach for normal operation.

The efficiency losses (fifth column) are considerably larger than the power losses, owing to the fact that the luminous flux decreases several times as fast as the power, when the temperature is lowered. At normal operation the efficiency losses owing to the cooling effect of the supports range from 4 per cent. for the carbon lamp to 13 per cent. for the tantalum lamp. At the reduced voltages at which measurements were made, the efficiency losses range from 5 per cent. for the carbon to 27 per cent. for the tantalum lamp. It is perhaps well to explain the exact significance of the efficiency loss. By this is meant the difference between the average efficiency of the filament as a whole, and the efficiency of its hottest, central portion. If there was no conduction of heat at the supports these two quantities would be the same; but, owing to the reduced efficiency of the parts of the filament near the supports, the central portion must be operated at a higher efficiency than would otherwise be necessary to secure a given average efficiency of the filament as a whole.

It should be emphasized that the results given above were obtained on single specimens of each type of lamp, and that the types of lamps were the standard types in commercial usage. Although it is thought probable that the percentage losses for other specimens of similar types would exhibit no marked differences in the magnitude of the losses, it would seem quite certain that other types of lamps would in general show different losses.

From a consideration of the curves given in Fig. 5, and the numerical results collected in Table 1, it would seem that the relatively large loss for the tantalum lamp is to be ascribed to the large number of supports, and the correspondingly short lengths of filament between successive supports. Although this is unquestionably the case, one is not justified in concluding *a priori* that the life of the tantalum lamp would be improved by reducing the number of supports and increasing the free length of filament. Other considerations of a practical nature enter, and

these must be given due weight in determining the most efficient construction. It is a matter of interest, however, to know specifically the magnitude of the losses in various types of lamps due to the conduction away of heat at the leading-in and anchoring wires.

Although complete measurements of the losses were made only at two voltages for each lamp, *viz.*, that of normal operation, and that corresponding to a color match with the carbon lamp at 75 volts, a series of measurements at intermediate volt-

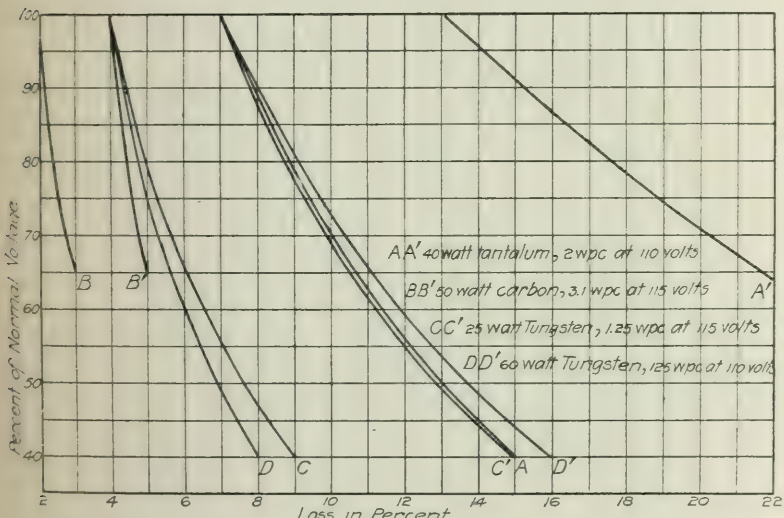


Fig. 7.—Variation with voltage of the energy (A B C D) and the efficiency (A′ B′ C′ D′) losses in four types of standard lamps.

ages was made which makes possible a fairly accurate interpolation for any voltage intermediate between the two voltages for which values are given. This series of measurements consisted in determining the loss at some one contact (the contact at one of the leading-in wires was chosen in every case) corresponding to a number of intermediate voltages, and assuming that the total loss at any voltage is proportional to the loss at this one contact for all voltages intermediate between the two extremes. The interpolation curve for each lamp is given in Fig. 7, in which ordinates are voltages expressed in percentage

of the voltage for normal operation and abscissas are percentage energy and efficiency losses respectively.

From Fig. 7 it is possible to compute the approximate energy and efficiency loss at any voltage, and thus to determine the corrections which must be applied to the measured lumens per watt at any voltage in order to obtain the true lumens per watt at which the central portion of the filament is operating. As the efficiency losses, particularly for some types of lamps, are fairly large when the lamps are operating at low voltage, the numerical results of selectivity as given in previous papers by one of the present authors et al. will need some revision. A full discussion of this point will be reserved for a future paper. Suffice it to say at present that the direction of the correction is such as to indicate a larger difference between carbon and metals in respect of the selectivity of their radiation than that given in the previous papers on this subject. Moreover, it is possible that the relative arrangement of the metals, as for example between tantalum and tungsten, may be altered somewhat, though this is not yet determined. The authors hope to repeat the original experiments, at least in part, in order to secure accurate results correcting for the losses due to thermal conduction and for such other losses as may affect the numerical results.

4. SUMMARY.

The results of the investigation of certain of the losses that occur in ordinary incandescent electric lamps may be summarized as follows, for those types of lamps which were studied.

1. Of the energy supplied to the lamp practically all is transformed into heat in the filament itself, only a small fraction of one per cent. being dissipated as C^2R loss in the leading-in and connecting wires.

2. Of the energy transformed into heat in the filament, that which is lost through the convection and conduction of heat by the enclosed gas is in all normal lamps entirely negligible.

3. The energy losses due to thermal conduction at the leading-in and supporting wires are quite appreciable for all types of lamps and for all voltages studied. The losses are larger for certain types of lamps, such as the tantalum lamp, than for

others, such as the carbon; and for all types the losses increase greatly as the voltage is lowered below that corresponding to normal operation. The energy losses at normal operation are relatively small, amounting, in the worst case studied, to only 7 per cent.

4. The efficiency losses due to thermal conduction are somewhat larger than the corresponding energy losses, and even at normal operation are as large, in the case of the tantalum lamp, as 13 per cent. Moreover, the efficiency losses increase rapidly as the voltage is reduced.

5. The principal element in determining the magnitude of the losses is the free length of filament between successive contacts.

6. The efficiency losses found are of such a character that there is no need for any modification in the general conclusions as to the selectivity of radiating metals which were arrived at in a previous investigation on the assumption that all the energy supplied to a lamp is transformed into radiant energy. The numerical results given in previous papers need some revision, and it is possible that the order of arrangement of the metals as to selectivity may undergo some change. The general conclusions, however, remain unaltered.

7. No measurements were made of the total energy losses which result from the absorption by the glass bulb and whatever deposit there might be on the inside of the bulb. The absorption by the bulb of the luminous flux from the filament is approximately 2 or 3 per cent. in new lamps, but may be very large in lamps which have burned a great many hours. No measurements were made of the losses either in total energy or in luminous flux due to the base of the lamp.

ENERGY STANDARDS OF LUMINOUS INTENSITY.[1]

BY HERBERT E. IVES.

All candle-power standards are devices for producing visible radiation of constant and measurable intensity. Existing or proposed standards secure this constancy of radiation by three methods. By the first method certain specifications as to the design and use of the radiator are closely followed, on the assumption that if these are adhered to the intensity of visible radiation will be determined. Standards of this type are represented by the candle, the Carcel, the Hefner and the pentane standards. In these a more or less definite and constant quantity of visible radiation per unit of time is obtained if the material and size of the wick, burner or chimney is according to specifications, if fuel of a certain composition is used, and if the atmospheric pressure and humidity have stated values. To this class would also belong primary standards formed of incandescent electric lamps of definite filament materials, filament length, vacuum and power consumption, were these feasible. All the primary standards in use to-day belong to this class. By the second method the intensity of radiation is controlled by the observation or measurement of some accompanying physical variable, such as temperature. In this class belong the Violle standard, and the black body standard proposed by Waidner and Burgess. In the former the unit is radiation from a square centimeter of platinum at its melting-point. In the latter the unit is radiation from an aperture of specified dimensions in a black body, the temperature being that of melting platinum as determined by a piece of that metal enclosed in or surrounding the black body. By the third method the intensity of visible radiation is controlled by direct measurement of the radiation, as radiation; for instance, with a bolometer. In this class belongs the three spectral lines standard proposed by Steinmetz.

From the standpoint of this classification it appears that the most striking characteristic of present standards is their indirect means of securing the end in view. They lie at one ex-

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treme, while at the other extreme lie the theoretically desirable ones, in which the quantity used is dealt with directly. Why the present standards are of the one extreme in type is not hard to see. The line of least resistance has been followed. By far the most pressing requirement has been *reproducibility*. It has been much easier to make a successful practical lamp of certain fixed and reproducible dimensions and call it a standard than to measure radiation. All the practical standards, in fact, date from the time when quantitative measurements of radiated energy were almost unknown, and before the relations between radiation and light were more than approximately understood. It cannot be said that even now quantitative radiation measurements can be made with the degree of accuracy necessary for a reproducible standard of light. Nor can it be said that the knowledge of the luminous equivalent of radiation is sufficiently exact to warrant the specifications of a light standard in terms of radiation, except in certain empirically determined cases. Nevertheless the theoretical possibility and the theoretical correctness of the third method mentioned above invite discussion.

Standards of this type are to be striven for because in them it is possible to connect the unit of luminous flux with the C. G. S. units. Thus it may be possible to specify the unit of flux as one watt of power per unit of area radiated in a certain way. The greater desirability of this mode of specification over the specification of burner and wick dimensions is sufficiently obvious.

It is the purpose of this paper to consider the theoretical and the practical side of standards of this type, namely, those in which the intensity of the radiation of the quantity of energy radiated in unit time constitutes the specification.[1]

These standards may be grouped as follows:

1. Those with continuous spectra.

   a. Specified by the quantity of total radiation.

   b. Specified by the quantity of "visible" radiation.

[1] In this paper the terms "quantity of radiation," "quantity of energy," "radiated power," "intensity of radiation," are used practically synonymously. In all cases "quantity of energy radiated per unit of time" is meant. This is somewhat clumsy and could be avoided by the term "rate of radiation," or "intensity of radiation," but neither of these terms convey clearly the idea of *quantity*, except to those carrying the exact scientific definitions in mind, that it is wished to keep to the fore.

2. Those with discontinuous or line spectra.
   a. Consisting of three wave-lengths, by the mixture of which all colors including white can be matched.
   b. Consisting of two wave-lengths by which white and some colors can be matched.
   c. Consisting of a single wave-length.

The theoretical and practical discussion of these standards is closely connected with several special topics: namely, the relation between radiation and light; the principles of color mixture; instrumental means for isolating radiations of the desired character; and methods of measuring light and radiation. A brief discussion of these is now necessary.

THE CONNECTION BETWEEN RADIATION AND LIGHT.

Any attempt to measure light as radiation, in power units, involves an accurate knowledge of the relationship between radiation and light. Light may be defined qualitatively as radiation which can be perceived by the eye. Quantity of light cannot, however, be identified with quantity of radiation, for there is a great difference in the magnitude of the visual sensation produced by different kinds of radiation. In photometry one is concerned with the brightness sensation produced by radiation. This is greatest for radiation of wave-length about 0.545 μ in the yellowish green part of the spectrum. From this point the brightness drops off to zero on the red side at about wave-length 0.75μ and on the blue side at about wave-length 0.38 μ. In most artificial illuminants the greater part of the radiation lies in the invisible spectrum on the long wave, or infra-red side; consequently they are very inefficient as producers of light. Were an attempt made to measure light by quantity of radiation a feeble light as many times greater than a bright one of different radiant character might easily be measured. Hence to measure light as radiation the weight to be given to radiated values must be accurately known in order to reduce them to light, considered on a scale of brightness. This is not a simple matter, for the brightness values of different colors vary both with different individuals and at different absolute illuminations. Furthermore, a serious difficulty arises in attempting to estimate or measure the relative brightness of different colors with any

degree of accuracy. In short, the whole problem of heterochromatic photometry is encountered. The complete coördination of light and power measurements must, therefore, wait upon the practical solution of that problem. Use can, however, be made of the present knowledge in order to form an idea of the probable conventions, methods, etc., by which must come the solution of the problem of measuring colored lights. It may be noted, then, that while there are differences in individual estimation of brightness, that average values can be obtained from numerous observers having the characteristics of the normal or average eye. According to the latest researches the variations due to changed illumination occur only at comparatively low illuminations; hence, if the standard condition of measure-

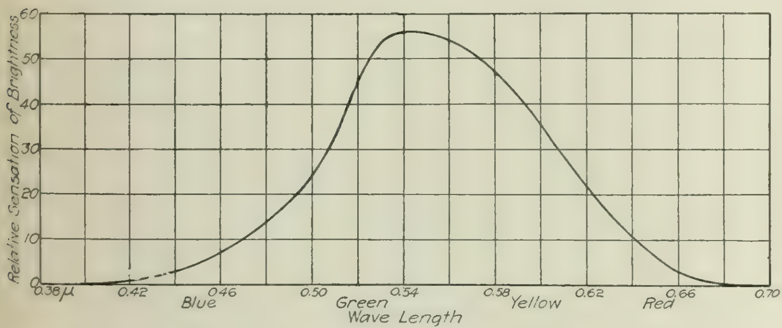


Fig. 1.

ment is that of high illumination. (10 meter candles or over) this difficulty may be minimized. The difficulty of making heterochromatic measurements may be met by making a large number of settings or by using special photometers. Probably the nearest approach to luminosity determinations of the spectrum of this character are those made by the writer and reported at the 1910 convention of this Society. The normal luminosity curve of the spectrum there given, obtained from the mean readings of five observers at high illumination, is shown in Fig. 1 and will be taken as the standard of reference in the present paper. This curve indicates that the radiation which gives the greatest sensation of brightness for a given quantity of radiation lies in the green of the spectrum at wavelength 0.545μ.

COLOR MIXTURE AND MEASUREMENT.

From the previous section it is evident that it may not be necessary for the eye to receive all the radiation from a light source in order that the latter may appear in its full brightness. But the mechanism of seeing is such that not only may the invisible radiations be dispensed with, but certain of the visible radiations may be dispensed with and yet receive the same quality of visual sensation. One may receive the sensation of yellow from a mixture of spectral red and green light, in which no true yellow light exists. From a mixture of pure red, green and blue the sensation of white may be received while other mixtures of these three reproduce with close fidelity all other spectral and natural colors. Use of this fact is made in the three-color process of color photography. One may also receive the impression of white from the mixture of various pairs of spectral colors, such as yellow-green, or red-peacock blue, may also be received; and tints intermediate between either of the two components and white may be matched.

Of greatest interest from the viewpoint of standards is the fact that these whites and colors are such only to the eye and as a consequence differ with different eyes. A white consisting of a continuous spectrum of the character given by the sun or an incandescent solid is white to all eyes, normal or color blind; but a two-color or three-color white may or may not match with this, depending on the observer. A partially red-blind observer, for instance, may receive little or no sensation from the pure red of the three-color mixture. It will be found therefore that the quantities of red, green and blue which mix to match a continuous-spectrum white will vary slightly with different observers. With an Ives colorimeter experience has shown that with normal observers differences of at least five per cent. in the mixing proportions of red, green and blue to match a continuous spectrum white may be expected. Considerably greater differences occur if any of the observers are abnormal to the extent known as "color blind." Color blind observers cannot, by the nature of their deficiency, make the same photometric settings as normal observers, except where lights of identical character are compared. Difficulty must necessarily arise in comparing va-

rious lights with a standard of different color, due to difference between observers, and this difficulty cannot but be increased by introducing a radical difference of spectral composition. Consequently any plans for standards or peculiar spectral character —such as those discussed below—must give serious consideration to this source of uncertainty.

As in the case of the luminosity values of the spectral colors, only by securing measurements from numerous observers could the characteristics of the normal eye with respect to color mixture be obtained. In the present case such data are not available in any great variety. The work of Koenig on the primary color sensations will be referred to as standard, although with the distinct understanding that his results are merely of the form needed, and not necessarily the values to be ultimately adopted as normal.

The chief facts in color mixture for the present purpose may be represented by means of color sensation curves, or in a color triangle. The mixing proportions of red, green and blue light are sometimes used as a measure of color. The proportions of a certain red, green and blue for every color of the spectrum can thus be obtained: these plotted against wave-length give what is called a "color mixture curve." Different curves are obtained, depending on the particular red, green and blue chosen. The intermediate colors, yellow and blue-green, are not exactly matched, for the mixture is slightly paler. Study of these phenomena has led to the point of view that there are no true primary colors, even in the spectrum, but that each spectral color is a mixture of three primary sensations called, for convenience, red, green and blue. A certain red, green, and blue, having the least admixture of the other two sensations are the purest spectral colors, the nearest approach to the true primary sensations with the possible exception of the red, green or blue perceptible immediately after fatiguing the eye to the two other colors. Finally the point is reached where the sensation of white is defined as equal excitation of these three primary sensations, and any color is defined in terms of these three *sensations*, rather than in terms of a particular red, green and blue *color*. In Figure 2 are given the primary sensation curves in the spectrum as de-

termined by Koenig. The areas included under the curves are equal, which means that the white spectrum gives white light. The sum of the red sensation ordinates at two or three wave-lengths gives the total red sensation in the mixture, and so for the other sensations. It is possible with these curves to pick out colors which mix to make white, and to determine the colors resulting from their mixture. The spectral colors which come nearest to being composed of one sensation alone are the red beyond 0.64μ, the green at 0.506μ, the blue at 0.480μ. These have the best claim of any red, green and blue to be called primaries.

A form in which these results may be put more conveniently for some purposes is the color triangle, shown in Fig. 3. The

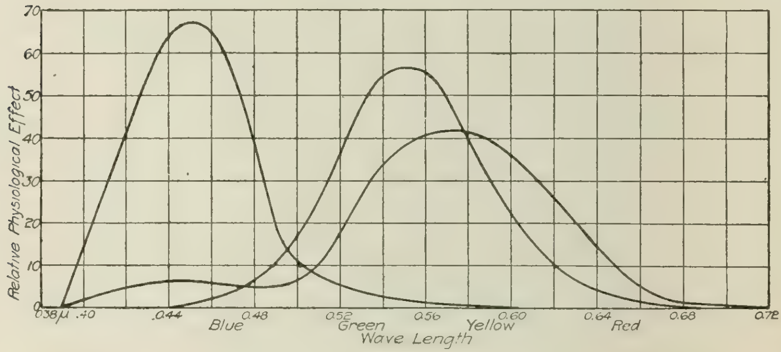


Fig. 2.

vertical distance of a point from a side indicates the fraction of the total color sensation which the sensation marked at the opposite vertex constitutes. In this figure all mixtures of two colors lie on the line joining them. Thus at once two colors can be picked out to make white, "complementaries," as they are called; what colors result from the mixture of these complementaries in other proportions can be studied; in short, most of the facts of color mixture represented by the curves may be learned, but in a quicker and easier way. The spectrum is shown by the curve. This lies some distance from the blue and green corners, because pure blue and green sensations are not represented in the spectrum.

The purest spectrum colors from the sensation curves have

been picked out; they may easily be found in the color triangle. They are the spectral colors nearest the vertical axes of the figure, namely, the blue at 0.4800μ, the green at 0.5060μ, and a red beyond the end of the spectrum, in other words a red as near the end of the spectrum as feasible. As the hue changes very little or not at all beyond 0.64μ any red beyond that point fulfills the requirements.

There is however another basis upon which selection of a red, green and blue might be made. It is evident from the color triangle that the lines joining the three purest colors (from the sensation standpoint) lie at different distances from the spectrum curve on the yellow and on the blue-green side. This means that the yellows formed by the mixture of this red and green are much more diluted with white than are the blue-greens. From the standpoint of securing the most saturated colors by mixture, therefore, a better choice might be made. The three colors forming the triangle which is symmetrically placed with respect to the spectrum are the colors indicated. They are the red and blue ends of the spectrum (or as near as it is feasible to work) and the green at about 0.52μ. These are the primaries for three-color photography.

The positions of a number of artificial illuminants are marked in the triangle. These are calculated from measurements in which "white" is taken as the spectral distribution of energy as calculated in a "black body" or completely radiating incandescent solid at 5,000° absolute temperature. In default of a better definition of white light this is here used.

INSTRUMENTAL MEANS FOR OBTAINING SPECIAL RADIATIONS.

Radiation of limited range of wave-length may be obtained in any one of three ways, or by combinations of these. The first is by choosing a radiator which emits only the radiation desired. No radiators exist which emit only a single wave-length, a single band in the visible spectrum, or two or three wave-lengths in just the position and proportion to meet the present demands. Only by using such radiators as approach this character, with proper auxiliary apparatus, can the desired end be achieved. The second way is by spectroscopic analysis and synthesis, whereby the

requisite radiations are separated or combined as desired. The third is by the use of absorbing screens to obstruct the undesirable radiations.

Two general methods of spectroscopic analysis might be used to produce radiation suitable for photometric purposes. One method is by projection of the light upon a screen, the other by receiving the light directly into the eye from the apparatus,—in which case the photometric screen is the prism face itself. The principle of the first method is illustrated by assuming a number of spectroscopes, each of which projects through an ocular slit a different portion of the spectrum upon a diffusing screen. This method, however, may be much simplified in its practical carrying out.

A and B (Figure 4) show diagrammatically two ways of pro-

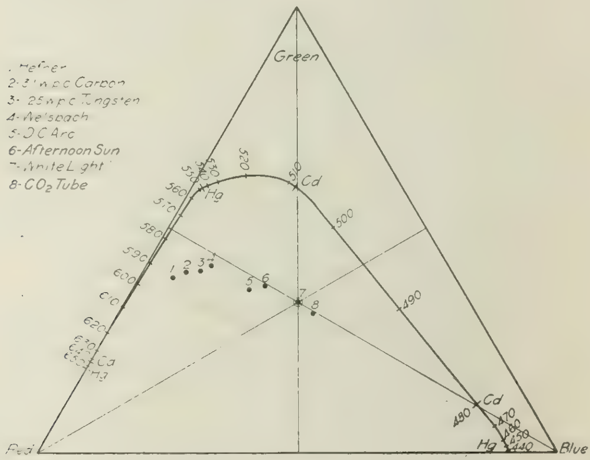


Fig. 3.

jecting portions of spectra. In the upper diagram A is a spectroscope (shown with direct vision prism for convenience); *a* is the slit, before which is placed the light source containing the desired and undesired radiations. At *b* is formed a spectrum on an opaque plate in which are cut slots corresponding in position to the desired wave-lengths and in width to the quantity needed of each. Over these slots is placed a lens of such focal length as to focus an image of the prism face upon a screen, S. This

image of the prism face is formed by the mixture of the radiations passed by the slots and by those alone. Such is the arrangement used by Abney in his color patch apparatus, for studying color mixture.

In the second diagram (B) is an alternative form available where the light source is extended. Here the slots are at the end near the source; the mixed light is formed at the single slit, *b*, and projected as before upon the screen, S.

In C (Figure 4) the arrangement just described is shown as used for direct observation of the prism face. The eye is placed

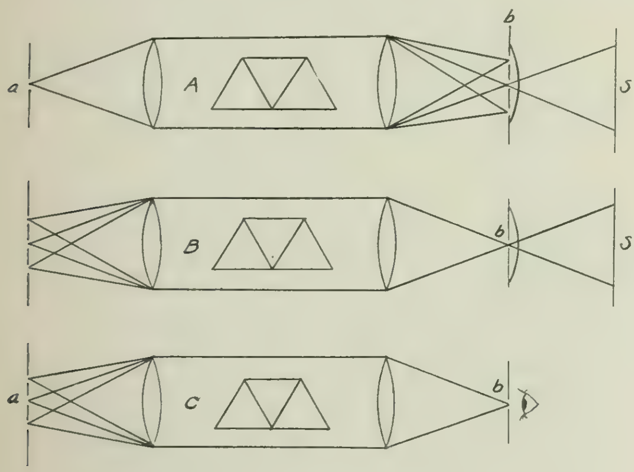


Fig. 4

at the single slit, *b*, where it receives all the light coming through the prism from the slits at *a*. This is the arrangement used by Maxwell in his "color box." Its chief advantage lies in the fact that the apparent illumination of the prism face is much greater than it is possible to obtain on an outside screen. This method can only be used with an extended source or with several sources placed over the slits, *a*.

In any of these devices the quantity of each radiation may be controlled by any ordinary means for reducing intensities, such as absorbing screens or sectored disks over the appropriate slits. In many cases the simplest control is by altering the widths of the

slits corresponding to the separate wave-lengths or spectral regions.

In practice great care must be taken to avoid the effects of scattered light. For illustration, in the arrangement C (Figure 4) each slit at *a* forms a spectrum at *b*, but only a portion of each spectrum is used. The remaining light in its passage through the instrument is scattered and reflected from various surfaces, so as to form a veil of light of different color from that which is alone needed from the slit in question. This trouble becomes especially marked when the desired radiation is faint compared with the others from the same source. If one attempts in this manner to obtain the red light from a quartz mercury arc, which is furnished by a very faint spectral line, it is necessary to have the arc so intense or the instrument slit so wide that the other radiations (yellow, green and blue) are of overpowering brightness and the light scattered from them almost completely blots out the red light.

The only easy escape from this difficulty is in the use of colored absorbing glasses over each of the slits. Alone, as noted below, these do not transmit light of sufficient purity for spectroscopic purposes, but glasses can usually be selected which will transmit only light of a quality near that of any one wave-length, and to prevent scattered light such glasses are applicable as auxiliaries to a spectroscopic device.

While in theory spectroscopic devices are ideal for separating radiations, they all labor under the disadvantage that considerable light is lost by reflection on the various surfaces, and by absorption in prisms and lenses. This loss may easily amount to fifty per cent.

Finally in considering the question of absorbing media, such as colored glasses, it will be found that, generally they transmit broad and ill defined spectral regions, as has been remarked, and alone are unsuitable for securing definite wave-lengths or wave-length intervals. They may, however, be used in conjunction with sources giving line spectra, for separating out the light from a single line or for preventing scattered light as described above. Certain substances have peculiar properties which make them of great assistance in special cases. For instance,

water has the property of absorbing quite completely a large part of the infra-red or heat radiation; glass obstructs the extreme ultra-violet; and the salts of the rare earths such as neodymium have peculiar narrow absorption bands which sometimes make possible the obstruction of individual wave-lengths in line spectra such as the mercury arc.

THE MEASUREMENT OF RADIATION AND LIGHT.

Both radiation and light are capable of measurement, each with a degree of accuracy dependent on the quantity available for measurement and upon the methods and conditions of measurement. Presently it is essential that the quantity of energy and the quantity of light to which it corresponds shall each be of such an order of magnitude as to be easily and accurately measured by the instruments and methods suitable for each kind of measurement.

First let the measurement of radiated energy by the bolometer be considered. In order to obtain an idea of the conditions that actually hold, reference is best made to a practical example, in which use is made of the present knowledge of the radiated power corresponding to luminous flux. A classic illustration of the measurement of radiated power is Angstrom's determination of the mechanical equivalent of the visible radiation of the Hefner. In making this determination there was involved a measurement of the power per square centimeter at a distance of one meter—a quantity which was found to be 0.00009 watt, with an error of less than 3 per cent. Since this measurement was made, more sensitive bolometers have been constructed and attention has been directed toward producing more nearly ideal surfaces or enclosures for receiving radiation in consequence of which a still greater accuracy might confidently be expected upon a redetermination. This may, however, be taken as a reference mark; that is, at least 0.0001 watt per square cm. of radiation should be demanded—and preferably more, in order that the measurement of radiation as radiation shall be practicable, and shall approach the one-half per cent. accuracy attainable on the photometric side.

In the case of the Hefner the total radiation, visible and invisible, was measured, while in this paper the measurement

of visible radiation alone is considered. How nearly does this quantity—0.0001 watt/cm^2—correspond to the energy radiated as visible light in any practical illuminant. According to recent calculations the most efficient possible light—that is, the one corresponding to the smallest quantity of radiated power, for the largest measured brightness—would be given by the green radiation of the mercury arc, and this would correspond to 800 lumens per watt.[1] In a laboratory experiment recently, the green light from a small quartz mercury arc 7 cm. in length was measured, the green radiation being separated by absorbing screens which will be mentioned later. From this arc approximately 50 candle-power of green radiation is obtainable. This illuminating surface at 20 cm. distance (where the illumination would be very close to uniform over an area large enough for either photometric or bolometric work) would give 0.125 lumen per sq. cm. or 0.00015 $\frac{\text{watts}}{\text{cm}^2}$. This is larger than the quantity measured by Angstrom, indicating that in this case sufficient visible radiation can be obtained to measure quantitatively as radiation, with an accuracy approaching that necessary. With a large quartz arc—such, for instance, as those being introduced for street lighting, much more energy would be available, which in turn could be nearly doubled by the use of mirrors, consequently considerably greater certainty of measurement is to be expected. The case considered, too, is that of the most efficient radiation: with less efficient radiation the quantity of energy would be larger; that is, the most unfavorable case has been considered. The illumination corresponding to this radiation is 1,000 meter candles and over, a quantity so large as illumination as to present no difficulty of measurement as light. It would in fact need to be reduced by sectored disc or other ordinary method for reducing illumination to make measurement easy, but this presents no difficulty and there is no objection to so doing.

Considering next the question of the measurement of light as such, the question of the intensity of illumination most desirable must be met, and it is necessary to know the relationship

[1] Discussion of paper on Luminous Efficiency, Chicago section, Jan. 13, 1911.

between the accuracy of measurement and the quality of light. As long as the standard and the light to be measured are identical in spectral composition, the choice of conditions or methods of measurement is of comparatively small import. With lights of the same color and spectral composition, the photometry being carried on at comfortable illuminations, an accuracy of one-half per cent. may be expected, using the Lummer-Brodhun contrast photometer. For the present this may be taken as the limiting accuracy necessary for all the measurements connected with a standard of light.

With lights of different colors the situation is much more complicated. The change in relative brightness due to changes in the illumination is encountered (Purkinje and allied effects), also the difficulty of choosing a method of measurement, and finally the differences in color vision which exist even between "normal" observers. All these difficulties increase as the difference in color increases. The Purkinje and similar effects are the easiest evaded, for it is only necessary to work at a moderately high illumination—ten meter candles or above—to be well beyond the range of illuminations in which the relative brightness of different colors varies seriously. The choice of a method or instrument of measurement is more difficult. Two methods only are seriously to be considered, namely the "equality of brightness" and the "flicker." Of these the latter is considerably the more sensitive and reliable. While the relationship between the criteria of these two methods is still not entirely settled, nor is it decided as yet which more properly deserves to be adopted as "right," it is probable that only by the use of the flicker method may be attained the accuracy for comparing lights of very different color, even should it be decided best to apply a correction factor to its readings. Lights as different in color as the green mercury radiation and the 4-watt lamp may be measured by the flicker photometer within an error of 1 per cent.

The differences in color vision between different observers present by far the most serious obstacle to the establishment of standards much different in color to existing ones. No matter what the method of photometry, there is no way to escape this difficulty short of calling upon a very large number of observers

of color vision found "normal" by test, and accepting the mean of their measures as that of the average eye. Doubtless such a process will ultimately have to be gone through, if the endeavor for accuracy and for standards of ideal character is carried to its logical end. It is important to know how great these differences may be in extreme cases. From data recently given by the writer, on the luminosity curves of the spectrum as obtained by five different observers of "normal" color vision, it appears that differences of as much as fifteen per cent. maybe found when monochromatic light, such as the green mercury radiation, is measured against the present "4-watt" lamp standard. With smaller color difference, the difference in measured values would be less; consequently there is great practical advantage in having standards near the quality of the lights to be measured.

Thus far attention has been devoted to a consideration of the methods of study, the methods of measurement, the tools and finally the varied difficulties connected with any attempt to establish a standard of luminous intensity specified in terms of quantity of radiation. It has been observed that the radiation corresponding to luminous flux is measurable by radiation meters, with some approach to the desirable accuracy, that is, with good prospect of attaining the accuracy of the photometric measurement. Radiation from existing radiators it is found may be analyzed and the analyzed parts afterward combined to produce special types of radiation to suit any theoretically desirable scheme, but that these analyses are subject to varying degrees of practical difficulty. From the study of color mixture and measurement, and the study of quantitative light measurement, it will be found that different degrees of accuracy and of feasibility pertain to the use of different characters of radiation. The farther a special type of standard departs in spectral composition from the illuminants to be measured, the greater will be the difficulties in its measurement as light.

In the light of this knowledge, the various radiation standards which have been outlined above remain to be considered. On the theoretical side desirability will be largely determined by the simplicity of the power-light relationship. On the practical

side desirability will be largely determined by the possibility of isolating the desired radiations, and by the ease of measurement, both as radiation and as light.

1. *Standards whose light consists of a continuous spectrum.*—Such would be furnished by incandescent solids, either the carbon particles in flames, the glowing surface of an incandescent mantle, the filament of an incandescent lamp, or the interior of a furnace at high temperature, *i.e.*, a black body. The chief characteristic of these sources of light is the very large amount of invisible or infra-red radiation, amounting to from 20 to 100 times the visible in quantity. The first class of these standards are:

a. Those specified by the quantity of total radiation.—The chief advantage of standards possessing continuous spectra is that they may be chosen of very near the color and spectral composition of most of the present illuminants. The problems of photometry are comparatively simple, at least for the present, and as long as heterochromatic photometry remains a comparatively unknown province, standards which almost entirely avoid facing that problem will undoubtedly possess a great advantage. If, however, the practical illuminants become very diverse in color this advantage cannot continue to pertain to so great a degree to continuous spectrum standards. The special advantages of measuring the total quantity of radiation are two,—first, the problem of separating out special radiations does not have to be faced; second, the quantity of energy available for measurement is quite large, which helps toward accuracy.

The disadvantages are several. There is no necessary or fixed connection in such a standard between the visible and the total radiation, that is, between the radiation and the light. Taking any one standard of this type, such as a flame, both the total radiation and the light will vary with conditions, and it is not true in general that both will vary together. In the case of flames where a large part of the variation is due to the varying size of the flame while burning, this may be nearly the condition. Sharp has done some interesting work on flame standards by following the simultaneous changes of light and total radiation. This work, however, was not quantitative in the sense here considered, for the absolute quantity

of radiation was not measured as it might be. In the case of an incandescent lamp, measurement of total radiation would certainly not be a reliable means of fixing the quantity of light because an increase of power input (and output) means an increased efficiency or change in the ratio of visible to total radiation. This leads to the statement of the most fundamental theoretical objection to attempting to specify a standard light of this type by the quantity of radiation; namely, that such a specification would hold only for one particular source at a definite temperature. A 40-watt tungsten lamp gives more light than a 40-watt carbon; a radiator at a high temperature has more visible radiation than a radiator at a low temperature giving the same quantity of radiation. In other words, the relationship between radiation and light is not a universal or unique one. It is at once evident that this fact makes it impossible to specify such a standard by quantity of radiation alone. Other variables,—either the composition of the radiator, or its dimensions, or its temperature, or the equivalent of temperature—must enter in. A specification of this type would be somewhat as follows: One watt per square cm. of the radiation of a black body (or other radiator) at a temperature of *a* degrees, is one lumen. Perhaps the simplest specification of this type would be: the unit of candle-power shall be the brightness of an aperture of unit area in a black body radiating energy at a certain rate, the latter to be measured by a bolometer. This specification fixes the temperature by the other variables. It cannot be claimed that there is in this case any apparent advantage in introducing the radiation measurement.

b. Continuous spectrum standards specified by the quantity of visible radiation.—These standards would differ from those just considered in having the infra-red absorbed or obstructed by one of the means considered above. In photometric work they would possess the same advantage as those because of their spectral character. One disadvantage pertaining to the ones just considered would not be present, namely, fluctuations in the infra-red independent of the visible radiation would have no effect on the measurement of the total radiation. But one of the most serious objections remains: there is no unique connection between quantity of radiation and light. Each illuminant,

depending on its color, would have a different light-power relationship. This reiterates the fact on which the author laid emphasis in a previous paper: the "mechanical equivalent" of light is a function of the quality of the light, varying from 800 lumens per watt for a yellow-green light to perhaps 5 lumens per watt for a Hefner. Consequently the radiation corresponding to one lumen of "Hefner light" would be much more than that corresponding to one lumen of "tungsten light." This would necessitate, as before, the specification of other variables such as temperature. Here too, for the first time, is encountered the difficulty of separating the desired radiation. This might be done spectroscopically by one of the means diagrammed above. In this case a serious difficulty would be encountered because of the large quantity of energy radiated in the deep red or ordinary illuminants. The slightest displacement of the obstructing screen would cause an error in radiation measurement much larger than the photometric errors and would yet cause no noticeable change in the quantity of light. The use of an absorbing screen such as water would simplify this problem, but at the expense of the definiteness of the spectral separation. A practical disadvantage of this type of standard over the previous one would be the much smaller quantity of radiation available for measurement.

The advantages to be expected from a standard specified thus do not appear large. In fact, both the types just considered appear on analysis to be incapable of complete specification by quantity of radiation, and hence do not completely conform to the characteristics that have been formulated for the third class of standards. In fact it is only in the next examples to be taken up—standards composed of spectral lines—that standards conforming completely to these characteristics will be found.

2. *Standards consisting of isolated wave-lengths.*—Such standards would be furnished most feasibly by radiators like metallic arcs whose spectra consists of isolated colored lines. The needful lines may be separated by absorbing screens or by spectroscopic means. A large number of metallic arcs are available, of varying degree of ease of working, of brightness and of steadiness. The fused quartz arcs of zinc, cadmium, mercury and several other metals of low melting-point are the most

promising for a problem of this sort. Spectroscopic means may also be employed to isolate narrow bands of colored light from sources whose spectra are continuous, in case no naturally isolated radiation of a desired wave-length can be found; but as a rule this is very undesirable because of the great loss of light.

a. Standards consisting of three spectral lines, whereby white and all other colors may be matched.—There are undoubted advantages in possessing standards of nearly the same color as the ordinary illuminants to be measured, that is, those varying from a yellow-white to white. The most general way to secure this condition without using a complete spectrum is to use three wave-lengths—red, green and blue. Steinmetz has suggested the use of red, green and blue lines from the mercury arc, so mixed as to make a white or a yellowish white, the intensity being specified in terms of the total quantity of radiation. He further suggests using the mixing proportions of these three colored lights as a measure of the color of the illuminant.

Approaching the problem from the start, without reference to previous suggestions or the question of practicability, the first matter to invite consideration is the choice of the best three wave-lengths. As noted above there are two bases for selection, one from the standpoint of purity in respect to the primary sensations, the other from the standpoint of purity in respect to color mixture.

The primaries from the first standpoint are a red of greater wave-length than 0.64μ, a green of wave-length 0.506μ, a blue of wave-length 0.48μ. It is of some interest to note that almost exactly these wave-lengths are furnished by an arc between cadmium electrodes. It is of further interest to recall that these three cadmium lines, red (0.6439μ), green (0.5086μ) and blue (0.4800μ) are the standards of wave-length, in terms of which the standard meter bar at Paris has been calibrated by Michelson. Should a three-line standard ever be considered seriously it would be worth while pondering upon the advisability of having the same source which furnishes our ultimate standard of length furnish our ultimate standard of luminous intensity as well.

The only reason that could be urged for considering the other

set of three-lines—the ones to form mixtures with the least dilution with white—would be that the three just considered will not mix to produce an exact match with the yellower of the present illuminants, for instance, the Hefner, which in the triangle lies outside the straight line joining the primary red and green. This objection would only be of moment were it proposed to actually match the measured illuminant or make measurements of its color in terms of the three-colors,—a proposition for which little support will be found. Moreover, there is no arc source giving the three wave-lengths that would be chosen for color mixture ($0.64\mu+$, 0.52μ, $0.45\mu-$) so that it has not the element of feasibility to be found in the cadmium primary standard.

Now as to the advantages and disadvantages of a three-line standard: one theoretical objection stands out clearly. It is, the same one found for continuous spectrum standards, that is, there is no unique power-light relationship. The quantity of radiation for a given quantity of light depends upon the particular red, green and blue chosen, for the efficiency of a subjective white varies with its composition. There must therefore be added to the specification of the quantity of radiation, the specification of the wave-lengths used, and, as well, the relative quantities of each kind of radiation. The latter requirement is exactly parallel with the specification of temperature in the cases just considered. That is, we cannot merely specify "a three-color white composed of so much radiated power." The nearest approach to making this kind of white of fundamental character would be to specify a three-color white, made by mixture of the three colors of the spectrum nearest the primaries, in a certain proportion, giving radiation in a certain quantity. Practically this might be achieved by the use of the cadmium arc.

Another basis of selection of one mixture over another might be that of efficiency; for instance, the most efficient possible three-color white might be selected. As a matter of fact, however, an attempt to discover the most efficient three-color white shows that this practically degenerates into a two-color white; in other words, the most efficient way to secure a mixed white is to approach two of the three lines (red and green) toward the most luminous part of the spectrum till they coalesce. The basis

of efficiency consequently need only be considered in connection with two-color white standards.

The question of practicability looms large in the three-line standard. Decision must be made as to the relative amount of red, green and blue that are to be used. Assuming that these may be easily regulated by instrumental means, the difficulty still remains that different quantities will be required by different people, so that the quantity of radiation corresponding to a given brightness will be different for different observers. In short here are encountered the difficulties due to difference in color vision in a form one degree more aggravated than in continuous spectrum standards, for they appear even when a perfect color match can be made. Should the standard be made white it would in color vary greatly from most artificial illuminants, and the difficulty of making brightness measurements would be somewhat serious. Should it be made yellowish, or a hue near that of present illuminants, a further arbitrary element would be introduced into the specification.

The greatest difficulty would perhaps be that of producing, separating and adjusting the proportion of the three radiations. It is doubtful whether any one metallic arc or any other source exists from which three radiations, red, green and blue, could be obtained in sufficient intensity to leave sufficient quantity to measure accurately after the process of spectroscopic separation and recombination. The cadmium arc is not of as high intrinsic brightness as would be advisable. The quartz mercury arc, while furnishing a green and blue line of considerable intensity, furnishes a red line of such small intensity that radiometric measurement has not been found possible.[1] The green and blue lines from a mercury arc and the red line of a cadmium arc might be a solution, but the practical difficulties would be immense. Separation of three lines by color screens is practically out of the question, for in all actual cases of red, green or blue lines, there are other neighboring lines in the spectra too close to be separated in that way. A spectroscopic device with three slits is therefore indispensable and this means loss of radiation, already small for measurement. Having separated the

[1] Ladenburg: *Phys. Zeit.*, 1904, p. 525.

three radiations, the most delicate problem of all arises, namely, that of securing the proper relative amounts of the three. This, of course, means making three radiation measurements, and unless the source or sources are of excellent steadiness, these three measurements should be made simultaneously with the measurement of the total radiation and of light. To those who have worked with spectroscopic and radiometric apparatus and with metallic arcs, the mere statement of these working requirements is sufficient to indicate a problem of almost helpless complexity, quite apart from the difficulties of the measurement as light.

The relative quantities of these three radiations which would make white (for a normal eye) may be calculated for any special case, for instance the three cadmium lines, or the red, green and blue mercury lines. To do this, use can be made of the color sensation curves, in conjunction with the energy curve of white light. For the cadmium wave-lengths we find that to 1 part of green radiation as it occurs in white light must be added 1.1 parts of red, and 1.2 parts of blue. In radiation quantities these correspond to 1 part of green, 1.11 parts of red, 1.15 parts of blue. The efficiency of this three-color white is slightly over 30 per cent. of the highest possible efficiency, and hence would be about 240 lumens per watt. For the mercury lines the radiation proportions are 10.4 red (at least[1]), 1 green, and 1.15 blue; its efficiency would be only a little over 9 per cent. or 75 lumens per watt.

In the following table are shown the percentages of the total radiation due to the three components of each of these three-

TABLE I.

Mercury arc, wave-lengths, 0.69μ, 0.546μ, 0.436μ

		Light	Radiation
Red	0.69μ	3.5%	83.5%
Green	0.546μ	92.1	8.5
Blue	0.436μ	4.4	8.0

Cadmium arc, wave-lengths, 0.644μ, 0.509μ, 0.480μ

		Light	Radiation
Red	0.644μ	17.6%	34.0%
Green	0.509μ	54.2	30.7
Blue	0.48μ	28.2	35.2

[1] (The luminosity value of this radiation is so low that both on the sensation and luminosity curves only an estimate of its value can be made. The figures used above are probably too favorable.)

color whites with the percentage of the total candle-power to each. It appears that the one using the mercury lines would be very undesirable from the fact that over 80 per cent. of the radiation is due to the red line which furnishes less than 4 per cent. of the light. As the quantity of radiation furnished by this line has been found too small to measure radiometrically, even in a quartz arc, this white does not appear feasible, even were it theoretically desirable. Were it possible to obtain sufficient radiation, the standard would be subject to the defect that a negligibly small variation in the total radiation might, if it were actually taking place in the green line, change the light value by a considerable fraction. In the cadmium white this defect is not present to anything like such an extent, in fact the required quantities of radiation are so nearly equal that the specification might with propriety be made "equal quantities of the red, green and blue cadmium radiations." This would further simplify the cadmium standard.

A word may be said as to the proposal to make the mixing proportions of the three standard radiations a measure of the color of the illuminant. One attractive but perhaps not very practicable possibility of a three-line standard would be to vary the three radiations so as to make an actual match in color with the measured light, as well as a match in intensity. If to each radiation were given its luminosity value for a normal eye, the sum of these would give the total intensity. This would of course demand that these luminosity values could be obtained for the average or normal eye, that they should be known for the observer making the measurement so that the values could be corrected to normal, and that the arithmetical summation of several different colored brightness should equal the measured brightness of the superposed radiations. The latter point can hardly be considered settled with sufficient definiteness at present to be confidently used. As to making the mixing proportions of three wave-lengths a measure of the color, it has been noted that the proper three-color measurement does not involve any particular wave-lengths but reduces all such measurements to the more fundamental *sensations*. Color measurements and brightness measurements are each sufficiently difficult, and involve

enough problems, to suggest that they are best performed separately.

In summing up the three-line standard, it cannot be said that it is at all promising as a possibility, nor does it possess many points of desirability. It does permit of making a standard of any desired color, but its specification is complicated both in the radiation-light relationship, which here is of chief interest, and in the manner of working out. In the latter particular as well, the practical difficulties, spectroscopic, radiometric and photometric, are exceedingly discouraging.

b. Standards of two spectral lines—If the desideratum is to produce a white standard, or a standard of a single tint such as yellowish white, two spectral regions or lines are sufficient. The difficulties of working with a two-color standard would be materially less than with a three-color standard. It is only necessary to have two suitable sources of radiation instead of three, and the relative energy measurements would be reduced from three to two. The difficulties introduced by color vision differences would probably be of about the same order of magnitude as with the three-line standard. The specification of light in terms of radiation is of course simpler, to what degree will be discussed in the following summary of three two-line standards. The three two-line standards are, first, the most efficient one, *i.e.*, the most efficient compound white light; second, the standard whose components are best fitted to match existing illuminants by their mixture in other than white light proportions; third, the standard formed of two lines of the same luminous efficiency.

The first two-line standard, the most efficient one possible, appeals to one from the standpoint of the simple and fundamental mode of specification in which the light-radiation is at once fixed. Which pair of wave-lengths correspond to this most efficient white light for the normal eye can be determined. All possible complementaries, taken from the color triangle, are given in Fig. 5, while in Fig. 6 are given their efficiencies in terms of the highest possible (yellow-green light), the longer wave-length of the two (red side) being used to indicate the pair of complementaries. The efficiency values continually rise as the redder

component becomes of shorter wave-length, until near the limit of the spectrum when it drops again rapidly. This efficiency is probably about 550 lumens per watt, considerably higher than the most efficient continuous spectrum white (330 lumens per watt).

The second two-line standard is interesting from the standpoint

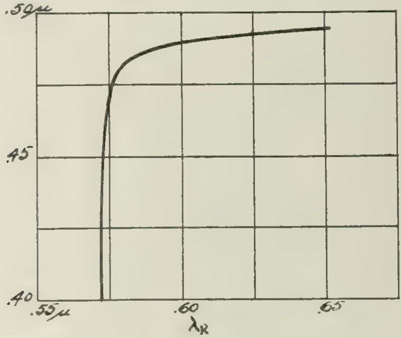


Fig 5.

of the color and photometric difficulties. Inspection of the color triangle of Fig. 3 reveals the interesting fact that all the more usual and agreeable illuminants, that is the incandescent solid ones, lie nearly upon a straight line through the center of the

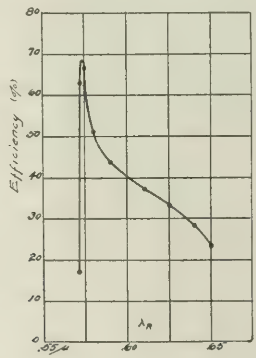


Fig. 6.

triangle. This means that two complementary spectrum colors may be found whose mixture in one proportion matches white, whose mixture in other proportions will closely match our ordin-

ary illuminants. With a two-line standard of this character the relative candle-power value of each set of proportions might be determined by measurements made by numerous observers. Thereafter the combination nearest in color to the secondary standard to be calibrated might be chosen, and the candle-power value obtained from the quantity of radiation, where the ultimate standard would be the candle-power value of the white given by this quantity of radiation from those wave-lengths. Such a proposition would be equivalent to using sets of calibrated tinted glasses; it is a simplification of the possible manipulation of the three-color standard suggested above. Its chief advantage would be from the standpoint of photometric difficulties, but it is at the sacrifice of simplicity in the radiation-light relationship. Wave-lengths for a standard of this type are 0.587μ and 0.486μ. The efficiency of the white combination would be about 370 lumens per watt.

The third two-line standard, in some respects the most interesting one, is composed of two lines of equal luminous efficiency, *i.e.*, equal brightness for the same quantity of energy. For the average eye here assumed, equal qualities of radiation wave-lengths 0.624μ and 0.493μ correspond to the same quantity of light, and at the same time are complementary. Now the chief interest of such a combination as this is that there is no necessity to specify the relative quantities of each wave-length. No matter in what relative proportions they are taken, the light equivalent remains constant. It is thus sufficient to secure the two radiations, combine them in any convenient proportions, and measure the total radiation. Were these two wave-lengths the same as those considered under the second two-line standard it would be almost all that could be desired. Unfortunately the color quality and the brightness quality are not interconnected in just this way in the eye. The chief advantage of this third two-line standard —and a very considerable one—would be that no instrumental means would be necessary to insure the proper proportions of the two components; they could be mixed to produce white as usually judged, and variations in different settings for white or by different individuals would come in as second order differences. The efficiency of any combination of the two wave-lengths 0.624μ

and 0.493μ would be 33 per cent. of the maximum or about 270 lumens per watt.

One phase has not been fully discussed in dealing with these two-line standards in their order, and that is the question of practicability, either in the production of these radiations or in their separation. A careful search through the available metallic arcs has had the disappointing result of showing that no pairs of lines having exactly the wave-lengths called for are to be found. Several white light pairs may be picked, for instance the mercury yellow lines 0.5770μ and the cadmium blue 0.4800 μ. The more interesting combinations could therefore be obtained only by cutting out portions of continuous spectrum sources. This practically amounts to ruling out these combinations on the ground of impracticability. They deserve some attention however from their theoretical interest and for that reason have been included.

c. Standards consisting of one spectral line.—Thus far there has been found but one case of a standard which could be specified entirely, so far as *quantity* of a variable is concerned, by the quantity of radiation, namely, the last two-line standard. All except this particular two-line standard involve specification of relative quantities of radiation at different wave-lengths, or temperature, or apparatus dimensions. On strict analysis, therefore, it belongs in the third division of our present classification, and consequently none of the others can make the scientific appeal that it can. In all of the three and two-line standards the difficulties of production, separation and measurement of the radiations, both as radiation and as light, are so great as to make questionable the desirability of attempting them.

In all the standards so far considered the advisability of the the integral color being white, or yellow-white, has been given chief weight. The reason for this has been the photometric difficulty, and great weight should by right be given to this, since the photometric work decreases in definiteness and accuracy quickly when differences of color occur. Nevertheless, in view of the very serious practical difficulties which are encountered in endeavoring to realize even the simplest of these standards, it is worth while to study the possibility of a one-line standard, if for no other reason than the chance that the practical difficulties,

other than those of photometry, might be small enough to counterbalance these latter in some measure.

It is in a one-line standard that the simplest possible relationship between radiation and photometric brightness is attained; and it is, in one particular, in a one line standard that the most desirable scientifically simple specification of a radiation standard is attained. This same standard is by remarkable coincidence absolutely the most feasible one from the standpoint of radiation measurement. This one-line standard is a *definite quantity of the most efficient possible radiation.* This radiation corresponds within the error of present determination to the green radiation of mercury. As already noted, this may be obtained from a quartz arc in sufficient intensity for both radiometric and photometric purposes, and, as will presently be seen, it is very easily isolated by color screens. In fact the chief purpose of this paper has been to lead up to this proposition, and the study of other types of standards has been largely to emphasize the peculiar advantages of this last.

The advantage from the theoretical side is its simplicity. It embodies the simplest possible light-radiation relation; it makes the "mechanical equivalent" of the most efficient possible light synonymous with the specification of the unit of light. The lumen, or its equivalent, becomes one watt per sq. cm. of the most efficient possible radiation. According to the present knowledge this would amount to about 800 of the present lumens, so that a decimal subdivision might be the practical unit. The lumens of any given source would be obtained at once by multiplying its watts by the "reduced luminous efficiency" of the source.[1]

From the standpoint of the measurement of radiation this proposed standard is extremely promising. From a properly designed arc probably 0.001 watt per sq. cm. may be obtained at a distance of 15 or 20 cm. from the source, due to this green radiation, a quantity easily measurable by a radiation meter, and much larger than is necessary for measurement as light. Moreover, no spectroscopic means are necessary for separating this green line from the others. A screen of neodymium nitrate or chloride or a sheet of neodymium glass obstructs the neigh-

[1] Luminous Efficiency, TRANS. Illum. Eng. Soc., p. 113, v. 5, (1910).

boring yellow line with remarkable completeness and sharpness. A solution of potassium bichromate in a glass trough obstructs the blue, violet and ultra-violet radiation. Water, nickel nitrate, copper chloride, copper sulphite, and iron ammonium sulphate are several solutions which very effectually cut out the infra-red and red radiations. It is therefore easy to prepare an absorption cell through which this green radiation passes in great intensity and entirely pure.

Up to this point the superiority of this particular one-line standard is overwhelming. When it comes to the photometric side, however, this standard is the least desirable of any. It would involve comparing a bright saturated spectrum color with the pale unsaturated colors of the usual illuminants. This immediately means that, with all psychological difficulties obviated, as by the flicker photometer, differences of as much as 15 per cent. may be expected between different observers of normal vision, as shown by some comparative measurements recently obtained in a laboratory. Adoption of such a standard would make it essential that the calibration of working standards should be done by some specified form of photometer, at a definite illumination, and that readings should be made by a very large number of individuals. A possible means by which this might be carried out is given in the following diagram.

The radiation from the mercury arc *a* passes through the absorbing solutions at *b*, and is incident upon the plane glass reflector *c*, part is transmitted to the surface bolometer *d*, to be measured as radiation; another part is reflected to the photometer screen *e* to be measured as light. At *f* is the secondary or working standard, for instance, an incandescent lamp. The advantage of such an arrangement is that a great part of the total radiation which must be present in large quantity for accurate measurement is used for the radiation measurement. The remaining part (about 10 per cent.) with a quartz mercury arc would be ample to secure an illumination of ten meter candles on the photometer screen.

Let it be assumed that the measurement of the radiation presents no difficulties other than the use of refined apparatus and careful manipulation, which is believed to be the case. The chief problems will then be the measurement of the radiation as

light, which could be done as suggested above, by having a large number, say 100, observers of normal color vision. Probably the only practicable instrument would be the flicker photometer. With this each observer could make a set of readings simultaneously with the measurements of radiation, thus determining the luminous flux per unit of radiated power for his eye. The mean of all observers would fix the true value.

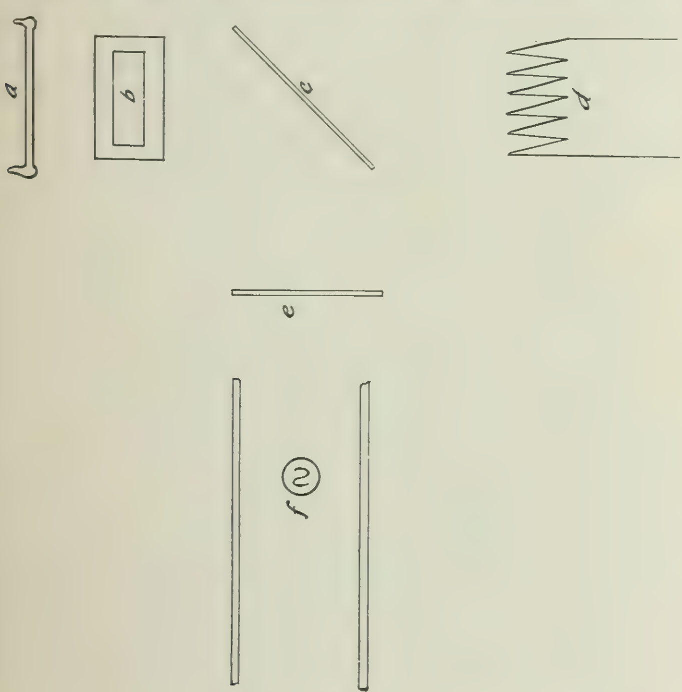


Fig. 7.

This latter measurement may appear very far removed from the realm of exact measurement. It involves, however, just the process that one must ultimately expect to go through, if standards of different colors are to be established. With a large number of observers the value obtained in one laboratory ought to be very close to that obtained in any other. It would simply amount to taking the difficulty of heterochromatic photometry by the horns. Probably the time is not yet ripe for so doing, but it is to be hoped that the next few years will so far clear up the

outstanding questions that satisfactory methods and conditions of measurement for light of different color may be agreed upon. The establishment of a standard by this method would be laborious, and unless the theoretical correctness of the standard were all that could be desired the procedure would have little to warrant it. It is, however, the author's belief that the "most efficient possible" radiation standard does have the elements of theoretical simplicity and correctness in such degree as to warrant boldly facing the difficulties of the light measurement involved, as soon as certain investigations upon photometry which are now under way have reached their conclusion.

CONCLUSION.

At this point the subject-matter of this paper can be summarized. Approaching the problem of photometric standards from the beginning, specification by quantity of radiation has been considered the most logical way. Considering the various paths by which this might be achieved one is led to the proposition that the simplest conceivable standard of luminous flux is defined as a certain density of radiation of the highest possible luminous efficiency. A practical means of achieving this is at hand. The difficulties of the photometric work increase in regular steps as this theoretically ideal standard is approached, and with it are greatest. But the unique advantages of this standard from every other viewpoint warrant far more the facing of these difficulties than do the slight advantages to be claimed for any other radiation standard. It must wait upon the solution of certain photometric problems, which are almost wholly those connected with heterochromatic photometry and this is a matter of time. But there can be no harm done by looking ahead and deciding upon the goal toward which we should aim. To do this has been the purpose of this paper.

DISCUSSION.

L. B. Eichengreen:—I would like to ask Dr. Ives for a description of the methods used in obtaining the color photographs shown on the screen.

W. J. Serrill:—Dr. Ives speaks of his proposed standard green light as being "simple." Is it his conception that such a beam

of light really is simple—that it is composed entirely of radiations of one wave-length? Also, does it mean that there is a greater number of waves to the unit area? What does a change in intensity mean in such a simple beam of light, and how is the wave-length measured?

M. S. White:—I would like to ask why, in the set of curves, the blue showed higher than the green?

W. H. Fulweiler:—I would like to ask Dr. Ives how he computed that color triangle; how he gets the three corners.

Dr. Ives:—About the computation of the color triangle: suppose we have an equilateral triangle. It is a property of this triangle that the sum of the perpendicular distances of any point from the three sides is a constant, and is equal to the altitude of the triangle. Take the color sensation curves. At any point in the spectrum one can determine the relative percentages of each sensation. If one calls the total of the sensations at any point in the spectrum unity, and the altitude of the triangle also unity, then by the proposition just stated, every point in the spectrum may be given a point in this triangle.

I can answer the question just before that by saying that the blue curve is not necessarily higher. It depends altogether on the scheme used in plotting. Here the three sensations are assumed equal in white light. But, if one represents, the sensations on the scale of brightness, the blue would be lowest. The red would be large, the green medium, and the blue would be quite small. The blue gives a very much smaller sensation of brightness than does the red, and also extends a shorter distance through the spectrum.

In regard to the question of the complexity, or simplicity, of any radiation, Mr. Serrill has touched upon one of the deepest problems in physics. It depends on the spectroscopic means at one's disposal whether a radiation may be called simple or not. The distribution of light in the cadmium lines used as standards of wave-lengths is the simplest known. There are no accompanying lines or satellites, and the light is restricted to a wave-length interval too small to be measurable by our present apparatus. The mercury green line consists of a central line and several smaller lines to each side, but so close that only in recent years have instruments been developed capable of de-

tecting them. For the purposes of the paper just presented, the mercury green line is the perfectly simple ray of which Mr. Serrill speaks.

In regard to the measurement of wave-lengths; this is done most simply by the use of a diffraction grating. By knowing the dimensions of the optical system and the spacing of the lines of the grating, the wave-length of light is determined much as a surveyor determines the height of a tower. As to what distinguishes an intense radiation from a faint one, the difference can best be expressed by saying it is the difference between a procession of children and a procession of adults, or of giants.

In regard to the question of color photography, it would be possible to give a whole lecture, or indeed a series of lectures on that by itself. However, in brief, the theory of three-color photography is, that one can select three primaries (a red, a green and a blue); from these one may find out in what proportion they mix to match the colors of the spectrum—red, yellow, green, blue, and so forth, and one gets what is called a "mixture curve." Three pictures are then taken through colored glasses which transmit the spectrum colors in the proportions indicated by the red curve, the blue curve and the green curve. These colored glasses are not the primary colors, they represent the mixing proportions of the three primaries. If pictures were taken for instance, by pure red, and by pure green, one would get no action by yellow light (which lies between in the spectrum), but if yellow is taken through the proper screen, one gets a certain amount of action through the "red curve" glass, and a certain amount through the "green curve" glass, and when each picture is viewed in the primary color there is obtained both green and red light, which mix to give yellow, and so on. That is the principle of this form of color photography.

T. J. Litle, Jr.:—In determining the color value of your Welsbach mantle, what cerium content did you have in the mantle, and what was the intrinsic brilliancy?

Dr. Ives:—Three-fourths of 1 per cent. cerium. Of the intrinsic brilliancy I have no measurements, but some recent measurements on a mantle of unknown composition gave 30 candle-power per sq. inch for the mantle as a whole.

F. N. Morton:—Dr. Ives has spoken very highly of the flicker photometer. In following up that subject I gathered the idea that the merits of the flicker photometer were something on the order of the Scotch verdict—"Not Proven," and I would like to ask what he thinks of that. Also, with reference to the Petavel standard, in which the rays are divided and passed through black fluorspar and through some transparent medium, and maintaining the radiant body—platinum for instance—at such a temperature that the radiation curves cross at a given point—I would like to know what he thinks about that.

Dr. Ives:—In regard to the flicker photometer not being proven. It has been shown, I think, or I tried to show it before the convention in Baltimore last fall, that as far as sensibility and reproducibility are concerned, it is far superior to the equality of brightness in working with lights of different color. That is, if one wants to obtain definite results in which the psychology of the observer is ruled out, one can do it with the flicker photometer. As to the exact relationship between the flicker photometer and the equality of brightness photometer, that is still to be determined. It may be necessary, if a flicker photometer is used, to apply a certain correction factor. But one problem is that of securing definite reproducible measurements, and in that respect I feel that the flicker photometer is in a class by itself.

In regard to the Petavel standard, it fills in an intermediate classification to those which I have given. In it, radiation is measured in a way. That is, radiation is used as a means of measurement. It appeals to me though as belonging really in the first and second classes, for after all, radiation is made use of principally as a means of fixing temperature and the dimensions of the radiation must be specified.

F. N. Morton:—What is the promise of it?

Dr. Ives:—Not much, I think.

W. J. Serrill:—Can you give us a more definite idea of what this proposed green standard would be like?

Dr. Ives:—Yes. I will refer you to the last figure of the paper for a possible method of carrying this out.

W. H. Fulweiler:—I would like to ask Dr. Ives whether he believes the work has gone far enough to lead him to think that the quartz mercury arc can be reproduced to give the same quality in that narrow band. In other words, there is no physical standard at the present time, as far as I know, containing articles of manufacture, that is not difficult to exactly reproduce. Impurities that are not observable by chemical processes, apparently have considerable influence on the value of the standard containing them. I have been wondering whether the character of the band given out by a quartz arc would be affected in the final analysis by the purity of the quartz, or mercury, or the condition of the electrodes, and whether after all we would not run into further difficulties.

Dr. Ives:—As to whether the band is a fixed and definite thing, the answer is unqualifiedly, yes. Isolated wave-lengths, of which the light of the sodium flame is a good representative, and the light of the mercury arc is another good representative, seem to be a fundamental characteristic of the radiating material. The only ways to change the wave-length of the radiation are either to place the source in an extremely magnetic field in which the wave-length charge is so small as to be detected only by the most powerful spectroscopes, or by extreme pressure on the source. Pressure gives a broadening or a very slight shifting of the spectrum lines. One other method by which wave-lengths may be changed is what is called the Doeppler effect caused by motion in the line of sight. For instance, in the case of a star coming toward us at a speed of many miles a second; this shift, too, can only be detected by the finest instruments.

The composition of the glass or quartz cannot enter into this proposed standard. The reproducibility of the dimensions or type of the mercury arc does not enter into it. The absorbing screen can have a wide range of latitude in its composition, and no exact specifications of thickness or other dimensions are necessary or significant. Standardization of apparatus comes in only in the question of the photometer; we can not avoid that. It will also probably come in the makeup of the bolometer; it may depend somewhat on the laboratory which makes it, that is,

on the individuality of the bolometer. I think it is reasonable to suppose, however, that bolometers may be made by different laboratories which will give results as consistent as can be obtained on the photometer.

Geo. S. Barrows:—If there should be any question about the reproducibility of that particular wave length, with the means that we now have at our command, the wave length could be accurately measured; then with the absorbing medium between the mercury arc and the bolometer, the wave length could be varied until, by measurement, we could get it to the pre-determined length. Is that correct?

Dr. Ives:—I do not know of any medium by which that wave length could be altered. The object of the absorbing medium is not to fix the position of that radiation, but merely to eliminate the radiations which come somewhere near it. As I have said, the wave length of such a monochromatic radiation is one of the unchangeable things in nature.

W. H. Fulweiler:—I feel that I should apologize for putting my question so badly. Dr. Ives has shown us that the bands or lines emitted by an element are characteristic of that element. My point was that it has been found that impurities present in a material under examination will sometimes give bands or lines lying close to those given by the pure material. This would have the tendency to render the lines or bands somewhat impure and variable, depending on the proportion and character of the impurity present. As these bands or lines would be very close to the mercury band, they would probably not be removed by the absorbing screens.

I am not familiar with the possibilities that might exist with the use of mercury, but I know that in the case of some of the rare earths, the presence of the lines close to minute quantities of impurities is a serious matter when the material is to be examined before the spectroscope. The identification of the normal lines for the pure material becomes very difficult.

Dr. Ives:—If impurities should produce any lines close to this mercury green line, so much so as to be difficult of spectroscopic separation, the chances are they would have practically no effect

on the result. They would all fall on the flat top of the luminosity curve: *i.e.*, they would all have the same luminous efficiency. No difficulty, however, is experienced in making up mercury which, for our purpose, can be called perfectly pure.

W. J. Serrill:—What is the wave-length of that green ray in terms of μ?

Dr. Ives:— 0.5461μ.

ARTIFICIAL LIGHT VERSUS SUNLIGHT FOR MAKING MOVING PICTURE FILMS.[1]

BY EDWARD L. SIMONS.

Manufacturers of moving picture films have observed that daylight is altogether too unreliable a source of illumination for their work. Accordingly they have been compelled to study the best adapted means of artificially lighting the moving picture studio. The consideration of such a problem constitutes this paper.

Standard practice requires an exposure of sixteen pictures per second. The cameras are nearly all arranged to move the film band for a period equal to that of its rest during the exposure, thus giving a possible maximum exposure of 1/32 second. The lens, however, has to be completely opened from the closed position and closed again from the full open position. These operations are performed by a shutter moving at a constant velocity and producing an efficiency of 70 per cent., thereby actually reducing the exposure to 1/46 of a second. The problem is further complicated by the conditions imposed by the required sharpness of definition which must be such that enlargements of 150 diameters and a depth of 12 feet or more can be obtained. Yet the working aperture of the lens cannot exceed F8, that is, this opening cannot be greater than one-eighth of the focal length. Moreover, the objects must be illuminated with an intensity sufficient to produce a fully timed negative in 1/46 of a second and with lens opening of F8. Obviously, to meet these requirements it is necessary, from a commercial standpoint, to have light of a known actinic quality and quantity rather than be compelled to depend on the practical knowledge of dark-room men to adapt the developer to each individual negative, a practice which is entirely at variance with twentieth century notions of standardizing manufacturing processes. Having thus briefly stated the problem the question of the most satisfactory artificial light may be considered.

Experience with artificial light in portrait studios has taught photographers that the monochromatic rendering of colors is

[1] A paper presented at a meeting of the Philadelphia section of the Illuminating Engineering Society, February 17, 1911.

most satisfactorily achieved by mercury vapor light. Arc lamps of various types are often used; but, although they permit of short exposures, they do not equal the photographic effect of the mercury vapor light. Use of mercury vapor light alone, however, will not permit the actors to effect the proper facial expressions which are so essential to good moving pictures. The

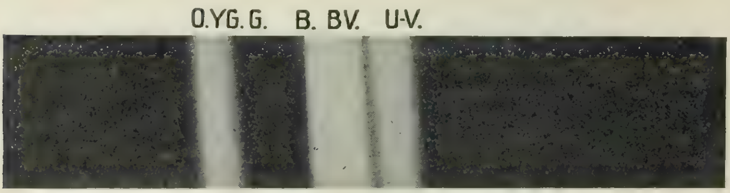


Fig. 1.—Photographic spectrum of mercury vapor light.

absence of the red rays, and the consequent ghastly appearance of the actors, preclude these effects. Therefore, to counteract the ghastly appearance of the actors, arc lamps are utilized in conjunction with the mercury vapor light required for the rapidity of exposure.

It might be interesting at this point to notice the reproductions of the photographic spectra of the latter illuminants. Fig. 1 shows the spectrum of the mercury vapor light as recorded by the usual photographic emulsion. This spectrum should be

Fig. 2.—Photographic spectrum of arc lamp.

compared with that of the arc lamp as shown in Fig. 2. In comparing these spectra, however, it should be remembered that the eye records red in a much larger degree than the photographic emulsion does.

Next to the quality of light required for moving picture studios, the quantity of the light is important. The light must be so diffused that the chalked faces of the actors and other

extreme high lights are eliminated. This is done by scattering the light with diffusers. By this is not meant filtering the light through translucent materials such as tracing cloth or ground glass, which are known to absorb a large amount of light; but to pass the light through prismatic glass having the prisms alternately arranged. The effectiveness of this method has been proved by a series of photometric tests. Moreover, it has been concluded that the maximum difference from the average intensity of the artificial illumination is only 20 per cent., whereas in the case of mixed artificial and daylight this maximum difference increases to 30 per cent.

It may be of interest to state, parenthetically, that in the par-

Figs. 3, 4 and 5.

ticular installation which the author has in mind the intensity on a plane of two feet averages 500 foot-candles. Some idea of the illumination required is had if one considers that the installation covers an area of 324 sq. ft. The total approximate useful light flux is, therefore, 162,000 lumens.

A practical example of the diffusion as well as the illumination intensity of the equipment so far described is barely discernible from the illustrations given below, the films of which (Figs. 3-5) were prepared from the first trial exposures made under this light. The films in the order in which they are shown were exposed respectively with lens openings of (Fig. 3) F4.5; (Fig. 4) F5.6; and (Fig. 5) F8; while all the lights—112 4-ft. mercury-vapor tubes and 20 arc lamps—were burning. The six small pictures

all show, indistinctly of course, an overabundance of light.[1] This test was made after sunset, and is, therefore, a true measure of the photographic power of the artificial light. Each pair of pictures (Figs. 3-5) represents a reproduction from one image of a series of exposures made with the latter-mentioned lens openings and while all persons were moving about. The films of the pictures in Figs. 6-8 were obtained by means of only the illumination from the 112 mercury-vapor tubes and with the same lens openings as in the first case. The pictures in Figs. 6-8 tend to show—possibly not perceptible from the pictures

Figs. 6, 7 and 8.

here reproduced—that the smaller lens openings yielded the best results and that arc lamps are not required from a strictly photographic standpoint.

The author observed recently a case where the unreliability of daylight was exemplified. For ten days he constantly endeavored to obtain a satisfactory interior exposure with sunlight but was unable to get one. A similar case, though more prolonged, was experienced in January, 1911. Of the twenty-seven work days, artificial light had to be used in the studio twenty days. Both these cases more than offset the arguments in favor of daylight for picture studios.

A brief description of the equipment as installed in the model studio of the Lubin Manufacturing Company is here appended

[1] The overabundance of light is more evident when the pictures are projected on a screen and enlarged 150 diameters, or upon examination of the original negatives. In either of these ways also a more marked difference between the pictures of Figs. 3-5 and Figs. 6-8 could be observed.

as a matter of interest. The equipment consists of six frames containing eight 48-inch mercury-vapor tubes. These are placed in two rows of three each parallel to the front of the stage, at an angle of thirty degrees and twelve feet above the floor. At the left hand side of the stage and at an angle corresponding to the line of view four more such frames are each suspended at the same height as the other frames and at an angle of forty-five degrees. These ten frames containing eighty mercury-vapor tubes are not equipped with diffusers. Directly under the latter four frames are four other frames which also contain eight mercury-vapor tubes each. They are placed in a vertical position twenty-four inches above the floor. The latter frames are equipped with diffusers, five feet square, built up of sections, one foot high, of ribbed glass, the ribs of the various sections alternating in vertical and horizontal directions. Just above the top of these frames and in a parallel line to them, eight arc lamps are suspended in pairs and are equipped with diffusers two feet square. In front of the stage, seven feet above the ground, there is suspended a row of twelve arc lamps which are equally distributed over a total length of fifteen feet. These arc lamps are also provided with similar diffusers. The arc lamps as well as all the mercury-vapor lamps are suspended in front of white enameled metal reflectors. Each frame of mercury vapor lamps is controlled by two switches, each switch controlling alternate tubes. Each arc lamp is controlled individually. The whole equipment is suspended from a skeleton framework, independent of the building, so that it can be enclosed whenever it is desired to entirely exclude daylight. Current is supplied by a motor-generator set. The motor is 2-phase, 250-h-p., and the generator is 150-kw., 3-wire 110-120-volt. This generator makes the conditions ideal, as the mercury vapor lamps are operated in multiple on 110 volts and the arc lamps at 220 volts.

The author wishes to acknowledge his indebtedness to Mr. L. J. R. Holst, M. E., for assistance in the preparation of this paper.

DISCUSSION.

Mr. F. H. Gilpin:—Is there any particular intensity of il-

lumination required upon the moving objects in the scenes to give the proper intensity in the film?

Mr. L. J. R. Holst:—Yes; unless there is a sufficient quantity of actinic light present, the resultant picture will be under-timed, and have all the faults of under-timing, such as an over-contrast of objects and lack of detail.

Mr. W. J. Serrill:—When you speak of "best daylight" I suppose you mean the best daylight you can get in the studio?

Mr. Holst:—Yes, of course.

Mr. Serrill:—I understood Mr. Simons to say that in January there were twenty days when he could not use the daylight; does that mean that in the studio there was insufficient light to take pictures?

Mr. Holst:—Yes, and I may add that not only in January, but even in June, July and August of last summer, it was practically impossible to make satisfactory exposures on many days.

Mr. C. O. Bond:—I would like to know something more of your skylights and their construction.

Mr. Holst:—The skylight is 162 ft. long, 60 ft. wide, 52 ft. high on the high side of the wall and 32 ft. on the low side. It has one immense glass roof, a continuous glass front, a glass side and a half-glass side. Owing to the fact that the high side, which is the west side of the building, is facing on 20th Street, it is essential that that side should not contain too much glass. It is all 3-way prism glass, and I may say that the diffusion is so perfect that with the brightest sun shining on the building, it is impossible to see a shadow anywhere but right under the sole of the shoe.

Mr. Geo. B. Muth:—How do you block out your skylight?

Mr. Holst:—We do not try to do that. We make a great number of exposures without considering the daylight that happens to be present. And, with reference to the photometric tests, we have shown that the electric intensity is very much greater than that of the daylight.

Mr. Norman Macbeth:—Did I understand from the first part of the paper that the artificial intensity averages 500 foot-candles?

Mr. Holst:—Yes,

Mr. Macbeth:—Also that the chief disadvantage of the arrangement of the light in the second set of pictures compared with the arrangement of the first set was the arrangement of the mercury tubes?

Mr. Holst:—No; it was the nature of the light spectrum.

Mr. Macbeth:—I suppose you are looking forward to doing color work. Is this light true for colors?

Mr. Holst:—No; I do not think it would be. I do not know that it will ever be attempted; if it is, it will have to be done by daylight.

Mr. Macbeth:—I remember the color film exhibit at the Garrick Theatre some time ago. I understood that the films there shown were taken with natural light, although there were some pictures of cut flowers which without an outdoor background one could not determine whether they were outdoor or inside exposures. I had thought that as an illumination problem this work was largely one of intensity and direction of light. Have you any comparative data of the intensity of your artificial light and day-light outside your studio on a clear bright day?

Mr. Holst:—No, we have no figures on that point, but I am guided to a certain extent by a knowledge of the openings in the lenses in making studio pictures. On a bright day we use about a F5.6 opening inside, and that would correspond on a similar day for an open view picture to about 11 outside, which would be about 1:4.

Mr. Macbeth:—I have found some very unusual installations lately which widen the possibilities for the use of incandescent mantle burners. It has not been generally known that it was possible to use gas light for photographic processes, because of the absence of the violet or actinic rays. In some studios in Philadelphia, mantle burners are being use to supplement the daylight arrangements, and very satisfactory results have been made possible on cloudy days or late afternoon sittings. I saw some pictures which were taken this week in cloudy weather, about 5 o'clock in the afternoon, the daylight being supplemented with the light from the mantle lamps. The

exposure was 4 or 5 seconds, but of course this could be shortened by increasing the intensity of the illumination. These portrait studios could not afford the elaborate and expensive electric lighting installation such as has been described in Mr. Simons' paper.

Mr. Holst:—Was a special mantle used?

Mr. Macbeth:—Just the standard incandescent inverted mantle lamps; the intensity on the subject from the gas lamps alone was less than 4 foot-candles which, considering the distance from the subject to the lamps, would be equivalent to 1,800 candle-power. The light was from the left, while on the right a 4-light fixture was installed in such a position as to soften the shadows on that side. In some cases a circular diffusing screen of cotton was used to tone down the light received from this fixture. They have been securing very satisfactory results indeed. One photographer won an award with work taken under these conditions in competition with the regular daylight studio product.

Mr. Serrill:—What purpose do the diffusers serve?

Mr. Simons:—To take care of the lower planes, and to graduate the light softly toward the right side of the stage.

Mr. Serrill:—Do the persons exposed to this light suffer from the intensity of the light?

Mr. Simons:—I have not heard any complaints, but without the arc lamps it would be pretty hard to go through a real love scene, because everybody would look sick.

Mr. Serrill:—Is that effect actually produced in the picture?

Mr. Simons:—No, it is not; but it affects the facial expressions of the people taking part.

Mr. Serrill:—Do the arc lights used in conjunction with the mercury vapor lamps counteract that effect?

Mr. Simons:—Yes, they do; and the actinic properties of the light are not affected.

Mr. C. O. Bond:—It is hard to believe than on a bright day, with the glass exposure that you have, that natural light is not stronger than the artificial light. I have understood that on a bright day the foot-candle illumination runs as high as ten thousand in the open. I remember Mr. L. B. Marks spoke on that subject in Baltimore last fall. In comparing the inside and out-

side illumination of factories he said that where there was only diffused daylight between high buildings as high as a thousand foot-candles were available. It is not the variation in the intensity of the illumination that troubles you, rather than the lack of it?

Mr. Holst:—That is a somewhat different field from ours. These photometric tests and quantities that you mention, are made with regard to brilliancy; that is of very little account as far as the chemical activity of the light or its photographic value in concerned. Its brilliancy I cannot question whatever. A light cloudy day is, photographically, much better than a bright sunshiny day; whereas in a photometric test there would be a great falling off on a cloudy day as compared with a bright sunshiny day. It is mostly the blue-violet section of the spectrum which affects the film, but which is of no account in this case.

Mr. G. R. Green;—Most of us here have, no doubt, seen the moving pictures which were exhibited last summer at the Garrick Theatre. Some of those pictures appeared almost perfect, while others had a "rainy-day" effect. I would like to know the cause of this streaky appearance, as it is very detrimental to the eyes of many people. The eyes become very sore after looking at the streaky pictures for a very short time, while the effect of the best pictures was both pleasing and agreeable. What was the cause of those poor pictures?

Mr. Holst:—These rainy-day effects as you call them—very properly too—are simply due to scratches on the films from frequent handling and particularly from passing behind the exposure window, where the are passed very rapidly It is simply the result of long use, and the films are worn out; the scratches become practically vertical lines, and interfere with the entire satisfaction that the film gives. It is merely a question of mechanical wear. On that account the films should be withdrawn.

Mr. Muth:—In the film which showed a lady with a fur coat, in a certain position she took there was a blurred image each time; why was that?

Mr. Holst:—That was owing to the fact that 16 exposures per second was not fast enough. If the manufacturers would gear

up the machines higher and make say 20 to 24 exposures per second, instead of 16, the effect would be correspondingly better. If during the exposure the image moves more than a 100th or 150th of an inch, which is permissible without being noticed, blurs are unavoidable.

Mr. Macbeth:—In photographic work foot-candle values are quite likely to be misleading. For instance, 5,000 foot-candles direct sunlight might not give as good negatives as a properly directed well-diffused artificial light of less intensity and actinic value. It is possible to have a high intensity on an illuminometer screen in direct sunlight, while in the shadows the intensity might not exceed a hundredth part of the maximum. An old rule in photography is to time for the shadows and let the "high lights" come as they may. The high sunlight illuminometer measurements which have been given at various times as indicative of the time of exposure for good negatives cannot, therefore, be considered.

Mr. Serrill:—Do you try to eliminate shadows?

Mr. Holst:—To a certain extent, yes. Of course, eliminating shadows entirely makes poor photographs. It is necessary to have a certain amount of them in order to get good pictures which can only be obtained by contrast between light and shade; but the strong shadows, such as sunlight produces, are, photographically, not desirable. You all have seen the effects on pictures produced at the seashore, possibly pictures of your friends, where there was a big black line overhead caused by the rim of a hat, and the lower section a chalky white, owing to the great intensity of the light. That can be avoided by softening the shadows.

Mr. Serrill:—You have a much geater illumination on one side than on the other?

Mr. Holst:—Much greater: I am absolutely certain that if that light had been made symmetrical and another side put up, the results would have been so very flat that no one would have cared to look at the pictures.

Mr. Bond:— I notice there is purposely left a short space or light strip between the pictures on the film; that is, I take it,

what produces the flickering effect. Would it not be possible to overlap the picture edges?

Mr. Holst:—Yes, it is possible, but that is not the cause of the flickering.

Mr. Bond:—Then these little strips do not show as you transfer from one picture to the other.

Mr. Holst:—No, because during the motion the shutter obliterates it. The flicker is due to the fact that while the picture is being placed on the screen in that position, the light on the screen is less than the general illumination while the picture is being projected. The shorter the period of motion, the longer the period of projection.

Mr. Serrill:—Does each picture come to a full stop?

Mr. Holst:—Absolutely; the least motion of the picture while it is on the screen would simply cause a blur.

Mr. F. N. Morton:—I notice the picture stands still for an instant while the shutter is open—while it is being projected; I should like to ask whether the device which provided a continuously moving strip was successful. As I understand it, they pass the film over a revolving prism which projects the picture on the screen in such a way that they do not have to stop it when the shutter is opened.

Mr. Holst:—That is quite right. Such a projector was made eight or ten years ago, but it was never placed on the market, as far as I know, probably on account of two reasons; first the cost, and second the considerable light absorption. Moreover, when the prism gets warm, it cannot possibly be kept true; it loses its sharpness of definition owing to the warping of the surfaces.

THE PHOTOMETRY OF MERCURY-VAPOR LAMPS.

BY JOSEPH C. POLE.

PART I.—ILLUMINATION GENERATED BY A LIGHT-LINE.

The investigations recorded below treat photometric problems of sources of light extended in form of straight lines only. These sources of light are here called "*Light-lines*" and are always supposed to be *straight* lines.

I. General Case.

Consider a surface arbitrarily defined and illuminated by a light-line of given length and a certain light intensity per unit length; the illumination generated in any element of this surface is to be computated. The light-line is supposed to be a mathematical line, that is, the light may be presumed as concentrated in the axis of the luminous tube, the diameter of the tube being neglected. Furthermore the light-intensity is assumed to be distributed continuously and uniformly over the entire length of the light-line. The latter supposition with mercury-vapor lamps, for instance, is neither generally nor exactly true; it will therefore be subjected to a closer study in the third part of the present paper.

The photometry of light sources in shape of straight lines as well as that of all other lamps, is, at present, based upon the punctiform source of light to which all definitions of light units are related and on the basis of which the customary photometers are developed. Therefore the following investigations are based on the *law of inverse squares*; further the *cosine law* is assumed as true.

The rectangular coördinate-system, in which the computations are to be performed, may be placed so that the x-axis coincides with the light-line A B, Fig. 1, and the origin with the centre of A B.

Let the light-line be L cm. long and emit J *candles per cm. normal to the axis*. Let the variable coördinate of the light-line

[1] A paper presented at a meeting of the New York section of the Illuminating Engineering Society, April 13, 1911.

be λ. Let, further, the surface, the illumination of which is to be determined, be defined by the equation

$$F(x, y, z) = 0. \qquad (1)$$

The differential $d\lambda$ of the light-line generates an illumination

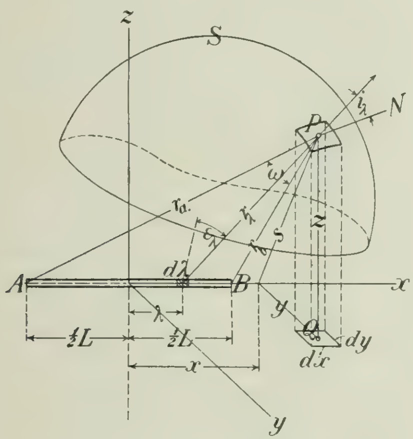


Fig. 1.—General photometric relations.

dE in the unit surface-element dS with the centre P (the coördinates of which must satisfy equation 1),

$$dE = J d\lambda \frac{1}{r_\lambda^2} \cos \epsilon_\lambda \cos i_\lambda \,. \qquad (2)$$

In this expression r_λ signifies the distance $P-d\lambda$, ϵ_λ the angle of emission and i_λ the angle of incidence. These quantities can be expressed as follows:

$$r_\lambda^2 = (x - \lambda)^2 + y^2 + z^2. \qquad (3)$$

$$\cos \epsilon_\lambda = \frac{\sqrt{y^2 + z^2}}{\sqrt{(x - \lambda)^2 + y^2 + z^2}} \,. \qquad (4)$$

The angle of incidence, that is, the angle between the line r_λ and the perpendicular N of the surface in point P, is determined by

$$\cos i_\lambda = \cos \alpha_n \cos \alpha_\lambda + \cos \beta_n \cos \beta_\lambda + \cos \gamma_n \cos \gamma_\lambda \,, \qquad (5)$$

where α_n, β_n, γ_n signify the angles of inclination of the perpendicular N, and α_λ, β_λ, γ_λ those of the line r_λ to the positive directions of the coördinate axes:

$$
\left.
\begin{aligned}
\cos \alpha_\lambda &= \frac{x - \lambda}{\sqrt{(x - \lambda)^2 + y^2 + z^2}} \\
\cos \beta_\lambda &= \frac{y}{\sqrt{(x - \lambda)^2 + y^2 + z^2}} \\
\cos \gamma_\lambda &= \frac{z}{\sqrt{(x - \lambda)^2 + y^2 + z^2}} \\
\cos \alpha_n &= \frac{\partial F}{\partial x} \cdot \frac{1}{\sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2}} = l \\
\cos \beta_n &= \frac{\partial F}{\partial y} \cdot \frac{1}{\sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2}} = m \\
\cos \gamma_n &= \frac{\partial F}{\partial z} \cdot \frac{1}{\sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2}} = n
\end{aligned}
\right\} \qquad (6)
$$

In substituting the terms of (6) in (5) there is obtained,

$$
\cos i_\lambda = \frac{1}{\sqrt{(x - \lambda)^2 + y^2 + z^2}} \left[l(x - \lambda) + my + nz \right],
$$

hence, according to (2) the illumination in P,

$$
E = \int_{\lambda = -\frac{L}{2}}^{\lambda = +\frac{L}{2}} J \cdot \sqrt{y^2 + z^2} \cdot \frac{l(x - \lambda) + my + nz}{\left[(x - \lambda)^2 + y^2 + z^2\right]^2} \, d\lambda.
$$

In this equation λ implies the variable, whereas the other quantities are constants for a certain surface element.

$$
E = J l \sqrt{y^2 + z^2} \int_{\lambda = -\frac{L}{2}}^{\lambda = +\frac{L}{2}} \frac{(x - \lambda) d\lambda}{\left[(x - \lambda)^2 + y^2 + z^2\right]^2}
$$

$$
+ J(my + nz) \sqrt{y^2 + z^2} \cdot \int_{\lambda = -\frac{L}{2}}^{\lambda = +\frac{L}{2}} \frac{d\lambda}{\left[(x - \lambda)^2 + y^2 + z^2\right]^2} \cdot \qquad (7)
$$

The two integrals are easily solved by introduction of the new variable μ:

$$\mu = \frac{x-\lambda}{\sqrt{y^2+z^2}}, \qquad d\mu = \frac{-d\lambda}{\sqrt{y^2+z^2}}$$

$$\int \frac{(x-\lambda)d\lambda}{[(x-\lambda)^2+y^2+z^2]^2} = -\frac{1}{y^2+z^2}\int \frac{\mu d\mu}{[1+\mu^2]^2}$$

$$= \frac{1}{2.[(x-\lambda)^2+y^2+z^2]} + \text{const.}$$

$$\int \frac{d\lambda}{[(x-\lambda)^2+y^2+z^2]^2} = -\frac{1}{(y^2+z^2)^{3/2}}\int \frac{d\mu}{[1+\mu^2]^2}$$

$$= -\frac{1}{2(y^2+z^2)} \cdot \frac{x-\lambda}{[(x-\lambda)^2+y^2+z^2]}$$

$$-\frac{1}{2(y^2+z^2)^{3/2}} \text{ arc tan } \frac{x-\lambda}{\sqrt{y^2+z^2}} + \text{const.}$$

$$E = \frac{J}{2}\, l\sqrt{y^2+z^2}\left|\frac{1}{(x-\lambda)^2+y^2+z^2}\right|_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}}$$

$$-\frac{J}{2}(my-nz)\frac{1}{\sqrt{y^2+z^2}}\left|\frac{x-\lambda}{(x-\lambda)^2+y^2+z^2}\right|_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}}$$

$$-\frac{J}{2}(my-nz)\frac{1}{y^2+z^2}\left|\text{arc tan } \frac{x-\lambda}{\sqrt{y^2+z^2}}\right|_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}}.$$

$$E = \frac{J}{2}\, l\sqrt{y^2+z^2}\left[\frac{1}{\left(x-\frac{L}{2}\right)^2+y^2+z^2} - \frac{1}{\left(x+\frac{L}{2}\right)^2+y^2+z^2}\right]$$

$$-\frac{J}{2}\frac{my+nz}{\sqrt{y^2+z^2}}\left[\frac{x-\frac{L}{2}}{\left(x-\frac{L}{2}\right)^2+y^2+z^2} - \frac{x+\frac{L}{2}}{\left(x+\frac{L}{2}\right)^2+y^2+z^2}\right]$$

$$+\frac{J}{2}\frac{my+nz}{y^2+z^2}\left[\text{arc tan } \frac{x+\frac{L}{2}}{\sqrt{y^2+z^2}} - \text{arc tan } \frac{x-\frac{L}{2}}{\sqrt{y^2+z^2}}\right]. \quad (8)$$

The formula becomes clearer by the following transformation :

$$E = \frac{J}{2} \frac{\sqrt{y^2 + z^2}}{\left(x + \frac{L}{2}\right)^2 + y^2 + z^2} \left[\frac{my + nz}{\sqrt{y^2 + z^2}} \cdot \frac{x + \frac{L}{2}}{\sqrt{y^2 + z^2}} - l \right]$$

$$- \frac{J}{2} \frac{\sqrt{y^2 + z^2}}{\left(x - \frac{L}{2}\right)^2 + y^2 + z^2} \left[\frac{my + nz}{\sqrt{y^2 + z^2}} \cdot \frac{x - \frac{L}{2}}{\sqrt{y^2 + z^2}} - l \right]$$

$$+ \frac{J}{2} \frac{my + nz}{\sqrt{y^2 + z^2}}$$

$$\cdot \frac{1}{\sqrt{y^2 + z^2}} \left[\text{arc tan} \frac{\frac{L}{2} + x}{\sqrt{y^2 + z^2}} + \text{arc tan} \frac{\frac{L}{2} - x}{\sqrt{y^2 + z^2}} \right].$$

Denoting in accordance with Fig. 1.

$$\begin{aligned} \left(x + \frac{L}{2}\right)^2 + y^2 + z^2 &= r_a^{\,2}, \\ \left(x - \frac{L}{2}\right)^2 + y^2 + z^2 &= r_b^{\,2}, \\ y^2 + z^2 &= s^2, \\ x + \frac{L}{2} &= k, \\ x - \frac{L}{2} &= k - L; \end{aligned}$$

and considering, that

$$\frac{my + nz}{\sqrt{y^2 + z^2}} = \cos i_s.$$

where i_s stands for the angle between line s and the perpendicular N, there is obtained

$$\begin{aligned} E = {} & \frac{J}{2} \frac{s}{r_a^{\,2}} \left[\frac{k}{s} \cos i_s - \cos \alpha_n \right] \\ & + \frac{J}{2} \frac{s}{r_b^{\,2}} \left[\frac{L - k}{s} \cos i_s + \cos \alpha_n \right] \\ & + \frac{J}{2} \frac{1}{s} \cos i_s \,.\, \text{arc}\, \omega. \end{aligned} \qquad (9)$$

Equation (8) or (9) represents a family of curves of equal illumination (equilucial lines) in surface S, when x, y, z are not taken for a determined point but are understood as variables connected by equation (1).

2. *Plane Parallel to Light-Line.*

Let the light-line A B, Fig. 2, be situated in a distance "a" above the plane of reference; polar coordinates, ρ, ϕ, may be used here as variable coördinates of the plane.

A differential $d\lambda$ of the light-line produces in the unit of a

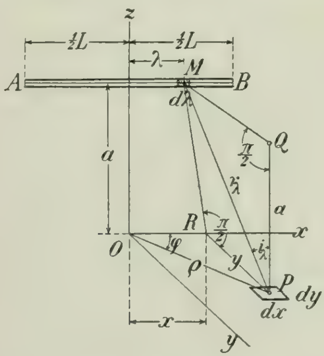


Fig. 2.—Light from line upon a parallel plane.

plane-element with the centre P, an illumination dE_1 equal to

$$dE_1 = J d\lambda . \frac{\cos \epsilon_\lambda \ \cos i_\lambda}{r_\lambda{}^2} = J a \sqrt{a^2 - \rho^2 \sin^2 \phi} \ \frac{d\lambda}{r_\lambda{}^4} . \tag{10}$$

According to Fig. 2 is further

$$r_\lambda{}^2 = \overline{PR}^2 + \overline{RM}^2 = a^2 + \rho^2 + \lambda^2 - 2\rho\lambda \cos \phi .$$

By denoting

$$a^2 + \rho^2 = b^2, \qquad 2\rho \cos \phi = c, \tag{11}$$

we get

$$E_1 = J a \sqrt{a^2 + \rho^2 \sin^2 \phi} \int_{\lambda = -\frac{L}{2}}^{\lambda = \frac{L}{2}} \frac{d\lambda}{[b^2 - \lambda (\lambda - c)]^2} . \tag{12}$$

$$\int_{\lambda=-\frac{L}{2}}^{\lambda=\frac{L}{2}} \frac{d\lambda}{[b^2 + \lambda(\lambda - c)]^2} = \int_{\lambda=-\frac{L}{2}}^{\lambda=\frac{L}{2}} \frac{d\lambda}{\left[\left(b^2 - \frac{c^2}{4}\right) + \left(\lambda - \frac{c}{2}\right)^2\right]^2}$$

$$= \frac{1}{2\left(b^2 - \frac{c^2}{4}\right)} \left[\frac{L\left(b^2 + \frac{L^2}{4}\right) - \frac{Lc^2}{2}}{\left(b^2 + \frac{L^2}{4}\right)^2 - \left(\frac{Lc}{2}\right)^2} \right.$$

$$\left. + \frac{1}{\sqrt{b^2 - \frac{c^2}{4}}} \text{ arc tan } \frac{L\sqrt{b^2 - \frac{c^2}{4}}}{b^2 - \frac{L^2}{4}} \right].$$

$$E_1 = \frac{J}{2} \frac{a}{\sqrt{a^2 + \rho^2 \sin^2 \phi}} \left[\frac{L\left(a^2 + \frac{L^2}{4} + \rho^2\right) - 2L\rho^2 \cos^2 \phi}{\left(a^2 + \frac{L^2}{4} + \rho^2\right)^2 - (L\rho \cos \phi)^2} \right.$$

$$\left. + \frac{1}{\sqrt{a^2 + \rho^2 \sin^2 \phi}} \text{ arc tan } \frac{L\sqrt{a^2 + \rho^2 \sin^2 \phi}}{a^2 + \rho^2 - \frac{L^2}{4}} \right]. \qquad (13)$$

As a special case of equation (13) there results, for points of the x-axis,

$$E_2 = \frac{J}{L}\left[\frac{2(1 - p^2 + q^2)}{(1 + p^2 + q^2)^2 - 4p^2} + \frac{1}{q} \text{ arc tan } \frac{2q}{p^2 + q^2 - 1} \right], \qquad (14)$$

and for points of the y-axis

$$E_3 = \frac{J}{L}\left[\frac{2q}{(1 + p^2 + q^2)\sqrt{p^2 + q^2}} + \frac{q}{p^2 + q^2} \text{ arc tan } \frac{2\sqrt{p^2 + q^2}}{p^2 + q^2 - 1} \right], \qquad (15)$$

in which terms

$$p = \frac{2\rho}{L}, \qquad q = \frac{2a}{L}. \qquad (16)$$

The illumination in the origin O, often called a measure of the "apparent horizontal candle-power" of the tube, can be deduced from (13) as

$$E_0 = \frac{JL}{2\left(a^2 + \frac{L^2}{4}\right)} + \frac{J}{2a} \text{ arc tan } \frac{aL}{a^2 - \frac{L^2}{4}}. \qquad (17)$$

If the angle ϕ be assumed constant and successively different values are bestowed on same, the equation (13) will then give the curves of illumination along the lines OP, from which curves the lines of equal illumination in the plane easily are constructed.

3. Photometry of Light-Lines.

The general equations (8) and (9) may now be applied to the case in which the perpendicular of the illuminated surface (plane) element passes through the centre of the light-line, Fig. 3. This case is of special interest in the art of photometry, the illuminated

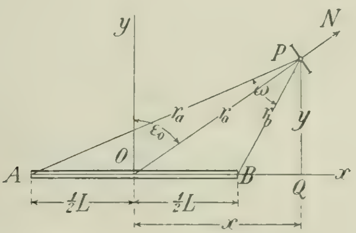


Fig. 3.—Light from line upon plane element normal to center line.

element of the plane in P representing then the photometer screen and the straight line OP the photometer axis.

The computation is to be performed in plane coördinates. Into the general equations are to be introduced:

$$z = 0,$$

$$s = y,$$

$$\gamma_\lambda = \gamma_n = \frac{\pi}{2},$$

$$\cos^2 \alpha_\lambda + \cos^2 \beta_\lambda = 1,$$

$$l = \frac{x}{\sqrt{x^2 + y^2}},$$

$$m = \frac{y}{\sqrt{x^2 + y^2}},$$

$$n = 0.$$

Equation (8) then assumes the form

$$E_4 = \frac{Jl}{2}\left\{ y \left[\frac{1}{\left(x - \frac{L}{2}\right)^2 + y^2} - \frac{1}{\left(x + \frac{L}{2}\right)^2 + y^2} \right] \right.$$

$$- \frac{y}{x}\left[\frac{x + \frac{L}{2}}{\left(x + \frac{L}{2}\right)^2 + y^2} - \frac{x - \frac{L}{2}}{\left(x - \frac{L}{2}\right)^2 + y^2} \right]$$

$$\left. - \frac{1}{x}\left[\text{arc tan}\, \frac{x + \frac{L}{2}}{y} - \text{arc tan}\, \frac{x - \frac{L}{2}}{y} \right] \right\}.$$

$$E_4 = \frac{J}{2\sqrt{x^2 + y^2}} \left[L y \frac{x^2 + y^2 + \frac{L^2}{4}}{\left(x^2 + y^2 + \frac{L^2}{4}\right)^2 - (Lx)^2} \right.$$

$$\left. + \text{arc tan}\, \frac{L y}{x^2 + y^2 - \frac{L^2}{4}} \right]. \qquad (18)$$

By substituting in No. 18 $x^2 + y^2 = \text{constant} = r_o^2$, one obtains the equations of the curve of light intensities of the light-line for a certain distance of the photometer screen. The curve has a cusp in the origin and the maximum in $[x = 0, y = \pm r_o]$:

$$E_{4\,\text{max.}} = \frac{JL}{2\left(r_o^2 - \frac{L^2}{4}\right)} + \frac{J}{2r_o}\, \text{arc tan}\, \frac{L r_o}{r_o^2 - \frac{L^2}{4}}, \qquad (18a)$$

which value is identical with that found in No. 17. In contrary to the punctiform source of light such a curve of light intensities cannot be derived from another curve of the same family by multiplication with a constant.

In introducing the quantities r_o, r_a, r_b, ω of the Fig. 3 we can also write (18) as

$$E_4 = J \,.\, \frac{yL}{4r_o}\left[\frac{1}{r_a^2} - \frac{1}{r_b^2}\right] + J \,.\, \frac{1}{2r_o}\, \text{arc}\, \omega. \qquad (19)$$

For distances r_0 of the photometer screen that are infinitely large in comparison to the length L of the light-line there will in (19) be approximatively

$$\frac{\text{arc } \omega}{r_0} = 0.$$

$$r_a = r_b = r_0 .$$

As $\frac{y}{r_0} = \cos \epsilon_0$, where ϵ_0 means the angle of emission, there is for great r_0

$$E_5 = \left(\frac{JL}{4r_0^2}\right) \cos \epsilon_0. \tag{20}$$

If the very great distance r_0 be supposed as constant and ϵ as variable, (20) represents the polar equation of two circles passing through the origin and having as diameters the sections $\pm \frac{JL}{4r_0^2}$ on the y-axis. Experimentally obtained curves of the light intensity in the meridian plane of mercury-vapor lamps show indeed, already at comparatively small distances r_0, a striking approximation to the circular shape.

Part II.—Computable Luminous Flux of a Light-Line.

4. *General Case.*

Attention will now be devoted to the investigation of another quantity, the knowledge of which is necessary for estimating the economy of luminous tubes, the calculable *total luminous flux* ϕ of a light-line. In order to calculate ϕ it is necessary to integrate on a surface entirely surrounding the light-line, the products of the area of each element of the surface and its intensity of illumination. In performing the calculations our former symbols and the coördinate system of Fig. 1 may be preserved.

The surface S surrounding the light-line may be defined arbitrarily by equation (1). Then the area of an element dS of S, the projections of the sides of which in the x-y plane are dx, dy, is given by

$$dS = \frac{dxdy}{\frac{\partial F}{\partial z}} \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2} \tag{21}$$

and the total luminous flux is, according to equation (7)

$$\phi = \int_x\int_y\int_{\lambda=-\frac{L}{2}}^{\lambda=\frac{L}{2}} J\left[(x-\lambda)\frac{\partial F}{\partial x} + y\frac{\partial F}{\partial y} + z\frac{\partial F}{\partial z}\right]\frac{1}{\frac{\partial F}{\partial z}}$$

$$\cdot\frac{\sqrt{y^2+z^2}}{[(x-\lambda)^2+y^2+z^2]^2}\,dx\,dy\,d\lambda.$$

$$\frac{\phi}{J} = \int_x\int_y \frac{\frac{\partial F}{\partial x}}{\frac{\partial F}{\partial z}}\sqrt{y^2+z^2}\,dx\,dy\int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}}\frac{(x-\lambda)\,d\lambda}{[(x-\lambda)^2+y^2+z^2]^2}$$

$$+\int_x\int_y\frac{y\frac{\partial F}{\partial y}+z\frac{\partial F}{\partial z}}{\frac{\partial F}{\partial z}}\sqrt{y^2+z^2}\,dx\,dy\int_{\lambda=-\frac{L}{2}}^{\lambda=\frac{L}{2}}\frac{d\lambda}{[(x-\lambda)^2+y^2+z^2]^2};\quad(22)$$

or according to (8), after reducing the terms in brackets

$$\frac{\phi}{J} = \int_x\int_y\frac{Lx\sqrt{y^2+z^2}}{\left(x^2+y^2+z^2+\frac{L^2}{4}\right)-(Lx)^2}\cdot\frac{\frac{\partial F}{\partial x}}{\frac{\partial F}{\partial z}}\,dx\,dy$$

$$+\int_x\int_y\frac{L}{2\sqrt{y^2+z^2}}\,\frac{\frac{L^2}{4}+y^2+z^2-x^2}{\left(x^2+y^2+z^2+\frac{L^2}{4}\right)-(Lx)^2}\cdot\frac{y\frac{\partial F}{\partial y}+z\frac{\partial F}{\partial z}}{\frac{\partial F}{\partial z}}\,dx\,dy$$

$$+\int_x\int_y\frac{1}{2(y^2+z^2)}\cdot\text{arc tan}\,\frac{L\sqrt{y^2+z^2}}{x^2+y^2+z^2-\frac{L^2}{4}}\cdot\frac{y\frac{\partial F}{\partial y}+z\frac{\partial F}{\partial z}}{\frac{\partial F}{\partial z}}\,dx\,dy.\quad(23)$$

In case the inclosing surface S be a *surface of revolution* with the (x axis) light-line as axis of rotation, that term simplifies itself. The meridian section of S in the x-y plane being defined by

$$y = f(x), \tag{24}$$

the illumination produced in a unit-element of S by a differential of the light-line is as per above

$$dE_r = Jy \cdot \frac{(x-\lambda)\cdot\dfrac{dy}{dx} + y}{[(x-\lambda)^2 + y^2]^2\sqrt{1+\left(\dfrac{dy}{dx}\right)^2}}\,d\lambda. \tag{25}$$

As the element ds of curve f has a length

$$ds = dx \cdot \sqrt{1+\left(\frac{dy}{dx}\right)^2}$$

the surface of revolution receives a total luminous flux of

$$\phi_r = \int_x\int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} 2\pi y\, ds\, dE_r = 2\pi J\int_x\int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} y^2\,\frac{(x-\lambda)dy + y dx}{[(x-\lambda)^2+y^2]^2}\,d\lambda,$$

or, according to equation (8)

$$\phi_r = \pi J\int\left[\frac{1}{\left(x-\frac{L}{2}\right)^2+y^2} - \frac{1}{\left(x+\frac{L}{2}\right)^2+y^2}\right]y^2\,dx$$

$$+ \pi J\int\left[\frac{x+\frac{L}{2}}{\left(x+\frac{L}{2}\right)^2+y^2} - \frac{x-\frac{L}{2}}{\left(x-\frac{L}{2}\right)^2+y^2}\right]y\,dx$$

$$+ \pi J\int\left[\text{arc tan}\,\frac{x+\frac{L}{2}}{y} - \text{arc tan}\,\frac{x-\frac{L}{2}}{y}\right]dx. \tag{26}$$

The integrals in expressions (23) and (26), after their limits have been calculated, will not, in general, reduce themselves to constant quantities, but will differ for different functions F, *f*. *Therefore the proposition of computing the total luminous flux of a light-line, in contrary to punctiform sources of light, is an indefinite problem, if the surface enclosing the light-line for which the luminous flux is to be calculated, be not simultaneously defined.* The total flux of a light-line obtained by calculation will not only be different for different species of inclosing surfaces, it will, as a rule, also vary within one family of surfaces from one surface to another.

In interpreting this conclusion it is to be remembered that the application of a surface enclosing the source of light is only an indirect aid for the calculation of ϕ, either for a pure mathematical computation as the above, or for figuring the mean spherical flux from curves of light distribution found by photometric observations.

The real physical flux of light as we would obtain it if we could measure the total energy radiated into space in form of light, is, evidently, independent of any imagined surface the light passes.

With the punctiform source of light there are no difficulties arising from the method of enclosing surfaces. But in applying the same method to extended sources of light and figuring the mean spherical luminous flux we will, as a rule, have to use different reduction factors according to the kind of enclosing surface.

To illustrate these conditions consider a special case:

5. Luminous Flux for a Co-axial Cylinder Surface.

The light-line A B, may according to Fig. 4, be placed in the center of a circular cylinder open on both sides. Such a case, for instance, is realized in certain rotary blue-print machines equipped with mercury-vapor lamps.

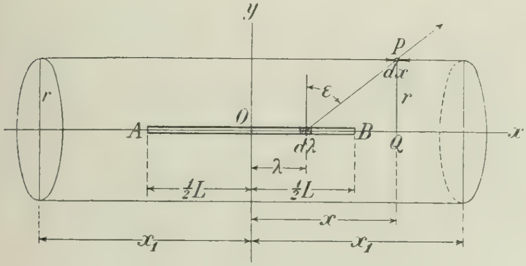


Fig. 4.—Light from line upon co-axial cylinder.

The flux sent by the light-line through the cylinder is

$$\phi = \int_{x=-x_1}^{x=+x_1} 2\pi r dx \int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} J d\lambda \frac{\cos^2 \epsilon_\lambda}{r_\lambda^{\,2}}$$

$$= 2\pi r^3 J \int_{x=-x_1}^{x=+x_1} dx \int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} \frac{d\lambda}{[(x-\lambda)^2+r^2]^2}$$

$$= \pi J r \int_{-x_1}^{+x_1} \frac{x+\frac{L}{2}}{\left(x-\frac{L}{2}\right)^2+r^2} \mathrm{d}x - \pi J r \int_{-x_1}^{+x_1} \frac{\left(x-\frac{L}{2}\right)}{\left(x-\frac{L}{2}\right)^2+r^2} dx$$

$$-\pi J \int_{-x_1}^{x_1} \operatorname{arc\,tan} \frac{x-\frac{L}{2}}{r} dx - \pi J \int_{-x_1}^{+x_1} \operatorname{arc\,tan} \frac{x-\frac{L}{2}}{r} dx \qquad (27)$$

The integrals are found as follows:

$$\int \frac{x \pm \frac{L}{2}}{\left(x \pm \frac{L}{2}\right)^2 + r^2}\, dx = \log_n \sqrt{\left(x \pm \frac{L}{2}\right)^2 + r^2} + \text{const.}$$

$$\int \text{arc tan}\, \frac{x \pm \frac{L}{2}}{r}\, dx = \left(x \pm \frac{L}{2}\right) \text{arc tan}\, \frac{x \pm \frac{L}{2}}{r}$$

$$- \frac{r}{2} \log_n \frac{\left(x \pm \frac{L}{2}\right)^2 + r^2}{r^2} + \text{const.}$$

After substituting these terms in (27) and calculating the limits the luminous flux passing the cylinder surface is found as

$$\phi_c = \pi J L \,\text{arc tan}\, \frac{2 r x_1}{r^2 - \frac{L^2}{4} - x_1^2}\,. \qquad (28)$$

In the case of an infinitely long cylinder, $x_1 = \infty$, (28) reduces itself to

$$\phi_{c\infty} = \pi^2 J L,$$

i. e., the total luminous flux is in this special case independent of the radius r.

If, however, the cylinder assumed is of a finite length, $2x_1$, and closed at both ends by circular surfaces, Fig. 4, the flux passing each of these end surfaces will be:

$$\phi_e = 2\pi J \int_{x=-\frac{L}{2}}^{x=+\frac{L}{2}} \int_{y=0}^{y=r} \frac{(x_1 - x)\, y^2}{[y^2 + (x_1 - x)^2]^2}\, dx\, dy$$

$$= \pi J \left[x_1 \,\text{arc tan}\, \frac{rL}{\frac{L^2}{4} - r^2 - x_1^2} - \frac{L}{2} \,\text{arc tan}\, \frac{2 r x_1}{x_1^2 - \frac{L^2}{4} - r^2} \right] \qquad (29)$$

Hence, the total flux for the closed cylinder, will be according to (28) and (29), after reducing the terms:

$$\phi_{c+2e} = \pi^2 JL + 2\pi J x_1 \arc\tan \frac{rL}{\frac{L^2}{4} - r^2 - x_1^2} . \qquad (30)$$

The deductions in paragraph 4 and the last example demonstrate sufficiently that, when computing the total luminous flux, it is necessary in theoretical photometry to determine a definite standard as basis of comparison of light-lines with punctiform sources of light. A method by which this may be accomplished will be shown in the following paragraph.

6. *Luminous Flux for Concentric Spheres.*

Let the x-axis of the rectilinear coördinate system be placed, as formerly, through the light-line, with its origin O in the center of light-line and sphere (Fig. 5) and let the nota-

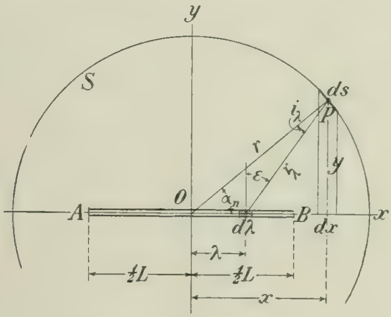


Fig. 5.—Light from line upon concentric sphere.

tions be the same as above. The luminous flux received by a spherical element with y as the mean radius and dx as height, is

$$d\phi_s = \int_{\lambda=-\frac{L}{2}}^{\lambda=\frac{L}{2}} 2\pi y\, ds\, dE_\lambda$$

and the illumination dE_λ of the unit surface of the spherical element is

$$dE_\lambda = J d\lambda \frac{1}{r_\lambda^2} \cos \epsilon_\lambda \cos i_\lambda$$

$$\cos \epsilon_\lambda = \frac{y}{r_\lambda}$$

$$\cos i_\lambda = \sin(\epsilon_\lambda + \alpha_n) = \frac{1}{r r_\lambda}[x(x-\lambda) + y^2]$$

$$d\phi_s = \int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} 2\pi J \frac{ds}{r} \frac{y^2}{r_\lambda^4}[x(x-\lambda) + y^2] d\lambda.$$

The equation of the meridian circle of P is further

$$x^2 + y^2 = r^2, \tag{31}$$

and a circular element is

$$ds = \frac{r}{y} dx \tag{32}$$

$$d\phi_s = 2\pi J \int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} y \cdot \frac{x(x-\lambda) + y^2}{[(x-\lambda)^2 + y^2]^2} dx\, d\lambda \tag{33}$$

$$\phi_s = 2\pi J \int_{x=-r}^{x=+r} \sqrt{r^2 - x^2}\, dx \int_{\lambda=-\frac{L}{2}}^{\lambda=+\frac{L}{2}} \frac{x(x-\lambda) - x^2 + r^2}{[(x-\lambda)^2 - x^2 + r^2]^2} d\lambda. \tag{34}$$

The integral of the illumination in (34) is already known:

$$\int_\lambda \frac{x(x-\lambda) - x^2 + r^2}{[(x-\lambda)^2 - x^2 + r^2]^2} d\lambda = -\frac{1}{2} \frac{x-\lambda}{(x-\lambda)^2 - x^2 + r^2}$$

$$- \frac{1}{2\sqrt{r^2 - x^2}} \arctan \frac{x-\lambda}{\sqrt{r^2 - x^2}} + \frac{1}{2} \frac{x}{(x-\lambda)^2 - x^2 + r^2} + \text{const.}$$

After computing the limits of this integral and substituting in (33) there is obtained

$$d\phi_s = 2\pi J \cdot \sqrt{r^2 - x^2}\, dx \left| \frac{\frac{L}{4}}{\left(x - \frac{L}{2}\right)^2 - x^2 + r^2} \right.$$

$$- \frac{\frac{L}{4}}{\left(x + \frac{L}{2}\right)^2 - x^2 + r^2} - \frac{1}{2\sqrt{r^2 - x^2}} \text{ arc tan } \frac{x - \frac{L}{2}}{\sqrt{r^2 - x^2}}$$

$$\left. + \frac{1}{2\sqrt{r^2 - x^2}} \text{ arc tan } \frac{x + \frac{L}{2}}{\sqrt{r^2 - x^2}} \right| .$$

$$\phi_s = \frac{\pi L J}{2} \int_{x=-r}^{x=+r} \frac{\sqrt{r^2 - x^2}}{r^2 - \frac{L^2}{4} - xL}\, dx - \frac{\pi L J}{2} \int_{x=-r}^{x=+r} \frac{\sqrt{r^2 - x^2}}{r^2 - \frac{L^2}{4} + xL}\, dx$$

$$- \pi J \int_{x=-r}^{x=+r} \text{arc tan } \frac{x + \frac{L}{2}}{\sqrt{r^2 - x^2}}\, dx - \pi J \int_{x=-r}^{x=+r} \text{arc tan } \frac{x - \frac{L}{2}}{\sqrt{r^2 - x^2}}\, dx. \quad (35)$$

The two last parts of (35) may be reduced in the following way:

$$\text{arc tan } \frac{x + \frac{L}{2}}{\sqrt{r^2 - x^2}} - \text{arc tan } \frac{x - \frac{L}{2}}{\sqrt{r^2 - x^2}} = \text{arc tan } \frac{\frac{x + \frac{L}{2}}{\sqrt{r^2 - x^2}} - \frac{x - \frac{L}{2}}{\sqrt{r^2 - x^2}}}{1 + \frac{\left(x + \frac{L}{2}\right)\left(x - \frac{L}{2}\right)}{r^2 - x^2}}$$

$$= \text{arc tan } \frac{L \cdot \sqrt{r^2 - x^2}}{r^2 - \frac{L^2}{4}} .$$

Moreover two new constants may be introduced:

$$\left.\begin{aligned} f &= \frac{r^2 + \frac{L^2}{4}}{L} \\ g &= \frac{r^2 - \frac{L^2}{4}}{L} \end{aligned}\right\} \tag{36}$$

Hence,

$$\frac{1}{r^2 + \frac{L^2}{4} - Lx} = \frac{1}{L(f - x)}$$

$$\frac{1}{r^2 + \frac{L^2}{4} + Lx} = \frac{1}{L(f + x)},$$

and equation (35) takes the form:

$$\phi_s = \pi J f \int_{x=-r}^{x=+r} \frac{\sqrt{r^2 - x^2}}{f^2 - x^2}\, dx - \pi J \int_{x=-r}^{x=+r} \text{arc tan}\, \frac{\sqrt{r^2 - x^2}}{g}\, dx. \tag{37}$$

In order to integrate the first part of (37), it may be resolved as follows:

$$\int \frac{\sqrt{r^2 - x^2}}{f^2 - x^2}\, dx = \int \frac{1}{\sqrt{r^2 - x^2}}\, dx + \int \frac{r^2 - f^2}{(f^2 - x^2)\sqrt{r^2 - x^2}}\, dx \tag{38}$$

$$\int \frac{dx}{\sqrt{r^2 - x^2}} = \text{arc sin}\left(\frac{x}{r}\right) + \text{const.} \tag{39}$$

For computation of the second integral in (38) the new unknown quantity $t = \frac{x}{r}$ is introduced and thus it is brought to the normal form of an elliptic integral of the third class with the modulus zero:

$$\int \frac{r^2 - f^2}{(f^2 - x^2)\sqrt{r^2 - x^2}}\,dx = \frac{r^2 - f^2}{f^2}\int \frac{dt}{\left(1 - \frac{r^2}{f^2}\cdot t^2\right)\sqrt{1 - t^2}}.$$

As is well known, this integral has the solutions

$$\int_0^t \frac{dt}{\left(1 - \frac{r^2}{f^2}t^2\right)\sqrt{1-t^2}} = \frac{f}{\sqrt{f^2 - r^2}}\arctan\frac{t\sqrt{f^2 - r^2}}{f\sqrt{1-t^2}}, \text{ for } r^2 < f^2$$

$$= \frac{t}{\sqrt{1 - t^2}} \text{ . . . . for } r^2 = f^2$$

$$= \frac{f}{2\sqrt{r^2 - f^2}}\log_n\frac{f\sqrt{1-t^2} + t\sqrt{r^2 - f^2}}{f\sqrt{1-t^2} - t\sqrt{r^2 - f^2}}, \text{ for } r^2 > f^2. \quad (40)$$

In (36) we denoted

$$\frac{r}{f} = \frac{rL}{r^2 - \frac{L^2}{4}} = \frac{\frac{r}{L}}{\left(\frac{r}{L}\right)^2 + \frac{1}{4}}.$$

The investigation in the first instance being restricted to spheres for which

$$\frac{r}{L} > -\frac{1}{2},$$

there is in this case $\frac{r}{f} < 1$ and in (40) therefore only the first solution need be considered. After reintroduction of the original unknown quantities, there is obtained

$$\int \frac{r^2 - f^2}{(f^2 - x^2)\sqrt{r^2 - x^2}}\,dx = -\frac{\sqrt{f^2 - r^2}}{f}\arctan\frac{x\sqrt{f^2 - r^2}}{f\sqrt{r^2 - x^2}} + \text{const.}$$

$$\int \frac{\sqrt{r^2 - x^2}}{f^2 - x^2}\,dx = \arcsin\left(\frac{x}{r}\right) - \sqrt{1 - \frac{r^2}{f^2}}\arctan\frac{x\sqrt{f^2 - r^2}}{f\sqrt{r^2 - x^2}}$$

$$+ \text{const.} \quad (41)$$

For computating the second integral in (37) the following quantities are introduced:

$$\frac{\sqrt{r^2 - x^2}}{g} = u$$

$$\frac{r}{g} = h$$

$$dx = -g \frac{u\,du}{\sqrt{h^2 - u^2}}.$$

$$\int \text{arc tan} \frac{\sqrt{r^2 - x^2}}{g}\, dx = -g \int \text{arc tan}\, u . \frac{u\,du}{\sqrt{h^2 - u^2}}, \tag{42}$$

and by partial integration,

$$-g \int \text{arc tan}\, u \frac{u\,du}{\sqrt{h^2 - u^2}} = g\sqrt{h^2 - u^2}\, \text{arc tan}\, u$$

$$- g \int \sqrt{h^2 - u^2} \frac{du}{1 + u^2}. \tag{43}$$

The $\int \frac{\sqrt{h^2 - u^2}}{1 + u^2}\, du$ can be found by the following resolution:

$$\int \frac{\sqrt{h^2 - u^2}}{1 + u^2}\, du = (1 + h^2) \int \frac{du}{(1 + u^2)\sqrt{h^2 - u^2}} - \int \frac{du}{\sqrt{h^2 - u^2}} \tag{44}$$

$$\int \frac{du}{\sqrt{h^2 - u^2}} = \text{arc sin} \left(\frac{u}{h}\right). \tag{45}$$

$$\int \frac{du}{(1-u^2)\sqrt{h^2-u^2}} = \int \frac{du}{h(1-u^2)\sqrt{1-\frac{u^2}{h^2}}} = \int \frac{dv}{(1-h^2v^2)\sqrt{1-v^2}},$$

$$v = \frac{u}{h}\,.$$

The latter integral is an elliptic one of the same species as (40) and its solutions are

$$\int_0^v \frac{dv}{(1-h^2v^2)\sqrt{1-v^2}} = \frac{1}{\sqrt{1-h^2}} \text{ arc tan } \frac{v\sqrt{1+h^2}}{\sqrt{1-v^2}}\,, \text{ for } h^2 > -1$$

$$= \frac{v}{\sqrt{1-v^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ for } h^2 = -1$$

$$= \frac{1}{2\sqrt{-1-h^2}} \log_n \frac{\sqrt{1-v^2} - v\sqrt{-1-h^2}}{\sqrt{1-v^2} + v\sqrt{-1-h^2}} \text{ .. for } h^2 < -1. \quad (46)$$

In (36) was

$$h = \frac{r}{g} = \frac{rL}{r^2 - \frac{L^2}{4}} = \frac{\frac{r}{L}}{\left(\frac{r}{L}\right)^2 - \frac{1}{4}}\,,$$

hence, if as stated above, there be considered only spheres the diameter of which is larger than the light-line, h always will be positive and in (46) there is always the first solution proper. By successively introducing the original quantities in (46) there is obtained :

$$\int_0^v \frac{dv}{(1 + h^2v^2)\sqrt{1 - v^2}} = \frac{1}{\sqrt{1 + h^2}} \text{ arc tan } \frac{u\sqrt{1 + h^2}}{\sqrt{h^2 - u^2}}$$

$$\int_0^u \frac{\sqrt{h^2 - u^2}}{1 + u^2}\, du = \sqrt{1 + h^2} \text{ arc tan } \frac{u\sqrt{1 + h^2}}{\sqrt{h^2 - u^2}} - \text{arc sin } \left(\frac{u}{h}\right)$$

$$\int_0^x \text{arc tan } \frac{\sqrt{r^2 - x^2}}{g}\, dx = g\sqrt{h^2 - u^2} \text{ arc tan } u$$

$$-g\sqrt{1 + h^2} \text{ arc tan } \frac{u\sqrt{1 + h^2}}{\sqrt{h^2 - u^2}} + g \text{ arc sin } \left(\frac{u}{h}\right)$$

$$= x \text{ arc tan } \frac{\sqrt{r^2 - x^2}}{g} - \sqrt{r^2 + g^2} \text{ arc tan } \frac{\sqrt{r^2 + g^2} \cdot \sqrt{r^2 - x^2}}{gx}$$

$$+ g \text{ arc sin } \left(\frac{\sqrt{r^2 - x^2}}{r}\right). \qquad (47)$$

By substitution of the results found in (41) and (47) into equations (37) there is finally obtained the total luminous flux for spheres with $r > \frac{L}{2}$:

$$\phi_{s_1} = \pi J \Bigg[f \text{ arc sin } \frac{x}{r} - \sqrt{f^2 - r^2} \text{ arc tan } \frac{x\sqrt{f^2 - r^2}}{f\sqrt{r^2 - x^2}}$$

$$+ x \text{ arc tan } \frac{\sqrt{r^2 - x^2}}{g} - \sqrt{r^2 + g^2} \text{ arc tan } \frac{\sqrt{r^2 + g^2} \cdot \sqrt{r^2 - x^2}}{gx}$$

$$+ g \text{ arc sin } \frac{\sqrt{r^2 - x^2}}{r} \Bigg]_{x = -r}^{x = +r}. \qquad (48)$$

Applying the equation (36), according to which $g^2 = f^2 - r^2$, the above expression can also be written:

$$\phi_{s_1} = \pi J \Bigg| f \text{ arc sin } \frac{x}{r} - \sqrt{f^2 - r^2} \text{ arc tan } \frac{x\sqrt{f^2 - r^2}}{f\sqrt{r^2 - x^2}}$$

$$+ x \text{ arc tan } \sqrt{\frac{r^2 - x^2}{f^2 - r^2}} - f \text{ arc } tg\, \frac{f\sqrt{r^2 - x^2}}{x\sqrt{f^2 - r^2}}$$

$$- \sqrt{f^2 - r^2} \text{ arc sin } \frac{\sqrt{r^2 - x^2}}{r} \Bigg|_{x = -r}^{x = +r} . \qquad (49)$$

The computation of the limits has, in order to avoid mistakes, to be done by approximation. Further there is to be kept in mind that the functions "arc sin" and "arc tan" are to be taken for a *single* revolution only according to the physical meaning of the equation. Thus:

$$\phi_{s_1} = \pi J [\pi f - \pi\sqrt{f^2 - r^2} - O - \pi f - \pi\sqrt{f^2 - r^2}]$$

$$= 2\pi^2 J [f - \sqrt{f^2 - r^2}] = 2\pi^2 J \, \frac{r^2 + \frac{L^2}{4} - r^2 + \frac{L^2}{4}}{L}$$

$$\phi_{s_1} = \pi^2 J L \text{ for } r > \frac{L}{2} . \qquad (50)$$

Before discussing this remarkable result, it will be well to calculate first the luminous flux for a sphere of $r \overset{=}{<} \frac{L}{2}$.

For $r = \frac{L}{2}$ there is

$$f = \frac{L}{2}$$

$$g = 0$$

and (37) changes for this instance to

$$\phi_{S_2} = \pi J \frac{L}{2} \int_{x=-\frac{L}{2}}^{x=+\frac{L}{2}} \frac{dx}{\sqrt{\left(\frac{L}{2}\right)^2 - x^2}} + \pi J \int_{x=-\frac{L}{2}}^{x=+\frac{L}{2}} \frac{\pi}{2}\, dx$$

$$= \frac{\pi}{2} JL \left[\text{arc sin } \frac{2x}{L} \right]_{-\frac{L}{2}}^{+\frac{L}{2}} + \frac{\pi^2}{2} J \Big[x \Big]_{-\frac{L}{2}}^{+\frac{L}{2}} . \qquad (51)$$

$$\phi_{S_2} = \pi^2 JL. \qquad (52)$$

For $r < \frac{L}{2}$ there is, according to (40):

$$\int_0^t \frac{dt}{\left(1 - \frac{r^2}{f^2} t^2\right)\sqrt{1 - t^2}} = \frac{f}{2\sqrt{r^2 - f^2}} \log_n \frac{f\sqrt{1-t^2} + t\sqrt{r^2 - f^2}}{f\sqrt{1-t^2} - t\sqrt{r^2 - f^2}}$$

$$\int \frac{r^2 - f^2}{(f^2 - x^2)\sqrt{r^2 - x^2}}\, dx = \frac{\sqrt{r^2 - f^2}}{2f} \log_n \frac{f\sqrt{r^2 - x^2} + x\sqrt{r^2 - f^2}}{f\sqrt{r^2 - x^2} - x\sqrt{r^2 - f^2}}$$

$$\int \frac{\sqrt{r^2 - x^2}}{f^2 - x^2}\, dx = \text{arc sin } \frac{x}{r}$$

$$+ \frac{\sqrt{r^2 - f^2}}{2f} \log_n \frac{f\sqrt{r^2 - x^2} + x\sqrt{r^2 - f^2}}{f\sqrt{r^2 - x^2} - x\sqrt{r^2 - f^2}} . \qquad (53)$$

Equation (46) keeps its former value, as h never becomes imaginary, and the total luminous flux, for $r < \frac{L}{2}$ is equal to

$$\phi_{s_3} = \pi J \Bigg[f \operatorname{arc\,sin} \frac{x}{r} + \frac{\sqrt{r^2 - f^2}}{2} \log_n \frac{f\sqrt{r^2 - x^2} + x\sqrt{r^2 - f^2}}{f\sqrt{r^2 - x^2} - x\sqrt{r^2 - f^2}}$$

$$+ x \operatorname{arc\,tan} \sqrt{\frac{r^2 - x^2}{f^2 - r^2}} - f \operatorname{arc\,tan} \frac{f\sqrt{r^2 - x^2}}{x\sqrt{f^2 - x^2}}$$

$$+ \sqrt{f^2 - r^2} \operatorname{arc\,sin} \frac{\sqrt{r^2 - x^2}}{r} \Bigg]_{x = -r}^{x = +r} \qquad (54)$$

This formula gives a complex term as the numerus of the $\log_n$ becomes negative. Then, too, the term loses its physical sense as the light-line, in that instance, is not inclosed by the sphere.

There is, therefore, in general, for concentric spheres of $r \geqq \frac{L}{2}$

$$\phi_s = \pi^2 JL.$$

So far as computations of the author on the subject show, the concentric sphere and the infinitely long circular cylinder seem to be the only surface-species which give as total flux a constant throughout the whole family of inclosing surfaces.

The quantity ϕ_s has also another signification, namely, that of the minimum value which ϕ in (23) will approach asymptotically when the surface inclosing the light-line increases infinitely. For infinitely large surfaces S the finite length of the light-line and the differences between the radii r become negligible, the meridian section of the photometric body of the light-line becomes according to equation (20) an exact circle, and the theoretical total flux ϕ, without regard to species of surfaces S, is then equal to

$$\phi_\infty = \pi^2 JL = \phi_s$$

as to the total flux for the infinitely large sphere.

The quantity $\phi_s = \phi_\infty$ being the only constant one, it is here proposed to *define the computable total luminous flux of straight-lines directly by* π^2 JL *and to accept this quantity as the comparison basis for the photometry of these sources of light.*

In order to determine the total candle-power of a light-line one would then have to perform only the one observation of the light-intensity J radially emitted by the unit length (1 cm.) of the luminous tube.

As J generally (with the exception of the quartz lamps) is comparatively low with present day lamps of a long-extended lighting body, one will, as a rule, prefer to read the light-intensity of the *entire* luminous tube placed normal to the photometer axis. After having thus observed the radial light-intensity E_o at a distance "a" between the center of the tube and the photometer-screen, (or "a" being measured by the tube length $q = \frac{2a}{L}$), there is obtained according to (17)

$$E_o = \frac{J}{L}\left[\frac{2}{1 + q^2} + \frac{1}{q} \text{ arc tan } \frac{2q}{q^2 - 1}\right]$$

and the mean spherical candle-power would then be

$$\phi_{\underset{\text{c.p.}}{x}} = \pi . E_o . \frac{L^2}{4} \left[\frac{1}{\frac{2}{1 + q^2} + \frac{1}{q} \text{ arc tan } \frac{2q}{q^2 - 1}} \right] . \qquad (55)$$

PART III. EXPERIMENTAL RESEARCHES ON MERCURY-VAPOR LAMPS.

7. *The Light Distribution along the Luminous Column of a Mercury-Vapor Lamp.*

While in the two preceding parts the investigations were general and were without any assumption as to the nature of the light, the third part of this paper will be devoted to mercury-vapor lamps especially and contains experimental investigations. Under "mercury-vapor lamp" only the lamp invented by Dr. Peter Cooper Hewitt is here understood, *i. e.*, a lamp with low vapor pressure.

In the introduction to the first part the light-intensity was assumed as being equally distributed along the entire luminous tube. However, with mercury-vapor lamps this assumption is not admissible without further investigation. On the contrary, it is, a priori, probable that the light intensity will be different in

the middle of the column from that toward the ends; for, the light-intensity of a mercury-vapor lamp depends in a high degree upon the vapor pressure, that is upon the local temperature. Now there is, in a mercury-arc, an over pressure on the electrodes and although the potential gradient in the luminous column is constant, the local temperature decreases from the electrodes toward the middle, because the electrodes, on account of the comparatively great energy converted there, are radiating heat to the luminous column. For this reason the above assumption must be modified.

The investigations undertaken to this end and described below were performed with a Bunsen photometer and a short mercury-vapor tube as comparison lamp in the following manner:

A stable mercury-vapor lamp, serving as a secondary standard, was installed on one end of a photometer bar 230 cm. (7.5 ft.)

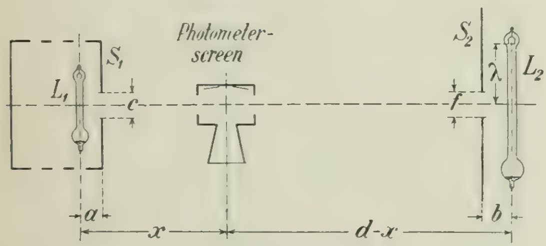


Fig. 6.—Arrangement of photometric apparatus.

in length. The lamp was inclosed in a large paste-board box, blackened inside and having toward the photometer screen, Fig. 6, a slot covered with glass, the width of which could be regulated longitudinally to the lamp tube between 10 to 50 mm. (0.4 to 2.0 in.). The box was provided with a thermometer and adjustable ventilating holes for maintaining a constant inside temperature. The other end of the photometer bar was limited by a large black screen (S_2 Fig. 6.) provided at the level of the photometric axis with a slot the height of which could also be regulated from 10 to 50 mm. The lamp-tube to be studied was suspended vertical and movable in clamps before the screen S_2. The Bunsen photometer was one of the usual kind with interchangeable side mirrors and diaphragms, but instead of the grease

spot a star-shaped cut in a piece of opaque paper covered with transparent paper, was chosen. Special care was taken in examining different sorts of paper until a paper thickness most favorable for the mean illumination, applied to the photometer screen, was obtained and until the tones of the transmitted and reflected light were well matched. The accuracy of reading thus obtained varied, according to the intensity of the illumination on the screen, between 0.1 to 0.5 per cent.

The above-mentioned secondary standard was a direct-current mercury-vapor lamp of the type shown in Fig. 7, of L = 10 cm.,

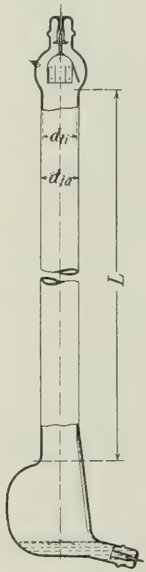


Fig. 7.—Type of experimental lamps Nos. 1, 2, 3.

d_i = 23 mm., with a normal current of 3.5 amp.; it was run on 2.5 amp. at a constant temperature of the box, thermometer reading 34 Cent., under which conditions it generated 2.66 international candles[1] r. p. cm. width of slot.

If a lamp like this one, before being used as standard, is run

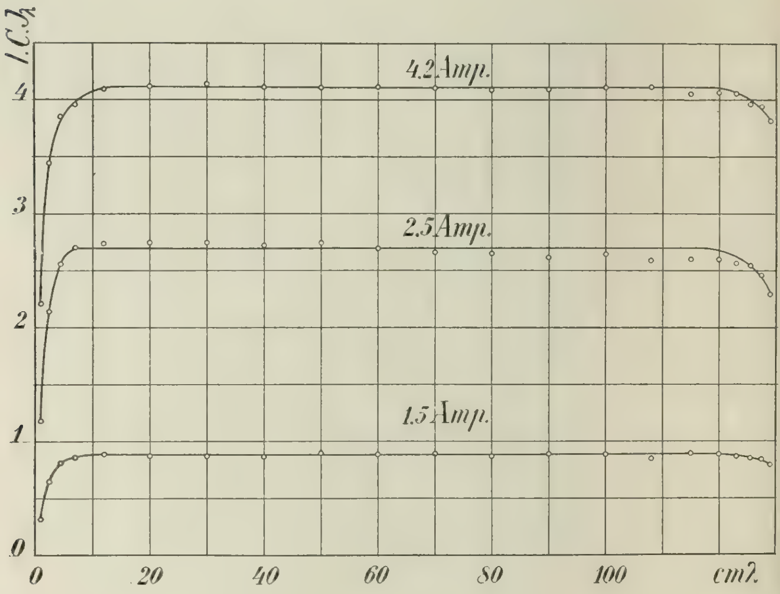
[1] Observed by comparison with a standard incandescent lamp as average of the following six readings, of which three were made by the author and three by his assistant: 2.65, 2.66, 2.69, 2.65, 2.64, 2.69, international candles. All light intensities referred to in this paper are figured in "international candles" (1 international candle = 1.11 Hefner candles.) The abbreviation c. r. p- cm. always means: candles radial, per cm. of luminous column.

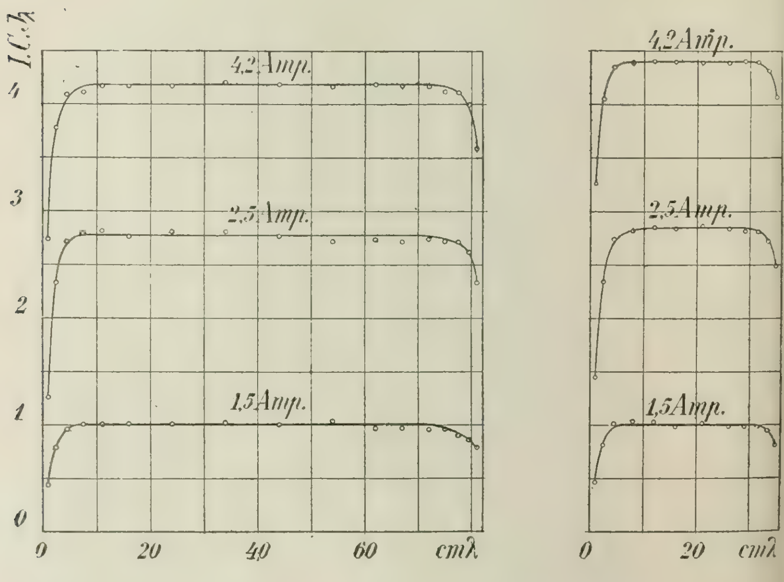
about one hundred hours at the normal current, in order to produce the first darkening of the glass, and then is kept below the normal current, it will represent, at constant current and invariable heat radiation, a very constant standard, easy to be regulated and very suitable for making observations similar to those recorded herein. The light-intensity of this standard lamp decreased within 300 running hours by 1.5 per cent.

In calculating the value of the readings obtained with such a photometer arrangement it is to be kept in mind that the examined lengths of the parts c, f, of the luminous tube Fig. 6, vary with the distance x of the photometer screen. Hence, the screen S_2 in Fig. 6 will not expose a constant length f of the standard lamp, but the strip $f \cdot \dfrac{d-x}{d-x-b}$. If therefore J represents the candle-power of the secondary standard per cm. of its luminous column and the other photometer distance be denoted as in Fig. 6, the candle-power of the lamp under examination per cm. of its luminous column will be found as

$$J_x = J \cdot \frac{c}{f} \cdot \frac{d-x}{x} \cdot \frac{d-x-b}{x-a}. \tag{56}$$

The lamp used for the investigations was a mercury-vapor lamp of the normal direct-current type, as shown in Fig. 7, with a luminous column 130 cm. (51.2 in.) in length made of one piece of glass as uniform in wall thickness and inner diameter as obtainable on the market. This lamp was suspended vertical before the slot of screen S_2. Then, while the current was kept constant, the tube was successively slid down and in each position the light intensity of the section f of the luminous tube, exposed by the slot, was measured, until the total luminous column from the positive electrode to the negative was thus photometered. Before taking any reading on them, the experimental lamp as well as the comparison tube, were run two hours at the respective current intensity until both lamps developed perfectly stationary conditions. For all observations in this section the width of the two slots was $c = f = 20$ mm. (0.8 in.). The tests were performed with three different intensities of the experimental tube, namely 1.5, 2.5, 4.2 amp. Then the same lamp was shortened one-third of its length and the light distribution along





Figs. 8a, 8b, and 8c.—Distribution of light intensity along luminous columns of lamps 1, 2 and 3.

its luminous column measured again under exactly the same conditions and current intensities as before. Subsequently the tube was again shortened by one-third of its original length and subjected to the same investigations.

The results are tabulated herewith and plotted in the curves of Fig. 8a, 8b, 8c. At the smallest current (1.5 amp.) the reading of the photometer was difficult, as at the small vapor pressure the light radiation was very sensitive to the slightest variations of current intensity and room temperature. The irregularities, which manifest themselves especially in the curves, are, however, not to be ascribed to that circumstance only; they are partly due to minute irregularities in wall thickness and inner diameter of the glass tube. In such a series of observations where special care was not taken in selecting the glass and where the tube, on account of great length, was composed of several pieces, the glass being incidentally very uneven, the light intensity along the luminous column varied so much that the variations of the tube diameter could be ascertained by a photometric reading such as the above, almost as exactly as with a micrometer.

By calculating, (by the Simpson's formula for instance) from Tables I to III, the average light intensity per cm. of length in the middle third of the luminous column, J_{λ_1}, and the average light intensity per cm. length for the whole lamp, J_{λ_2}, the values of Tables IV, are obtained. From this it will be seen that for the lamp investigated the ratio $\frac{J_{\lambda_2}}{J_{\lambda_1}}$ comes in between the limits 0.944 and 0.991, and on an average amounts to 0.978. Probably $\frac{J_{\lambda_2}}{J_{\lambda_1}}$ is the greater the longer the luminous column is.

Summing up, it may be said that:

The light intensity of a mercury-vapor lamp is not equal along the entire luminous column. It is constant and of the greatest intensity in the middle third and decreases near the

electrodes. The ratio of the mean local light intensity of the entire luminous column to the light intensity of the middle third may, for practical purposes, be taken with 0.98.

If, then, in the former computations, J is supposed to have been measured in the middle of the lamp, a correcting factor of 0.98 must be introduced in the formulas.

TABLE I.—Experimental Lamp No. 1.

Length of luminous column L = 130 cm. Average diameter of tube inside $d_{ti} = 2.31$ cm. Average diameter of tube outside $d_{to} = 2.53$cm.

λ = Distance of center slot from positive electrode (see Fig. 6). J_λ = Local radial light intensity per cm. of the luminous column. i = Lamp current. e = Potential difference between electrodes. t = Mean room temperature.

λ cm.	i = 1.50 amp. e = 89.0 volts t = 20 centigr.	J_λ Intern. candles r. per cm.	i = 2.50 amp. e = 81.5 volts t = 24 centigr.	J_λ Intern. candles r. per cm.	i = 4.20 amp. e = 74.5 volts t = 23 centigr.	J_λ Intern. candles r. per cm.
1.0		0.32		1.18		2.21
2.5		0.65		2.14		3.44
4.5		0.81		2.56		3.85
7.0		0.86		2.70		3.96
12.0		0.88		2.73		4.09
20.0		0.87		2.74		4.12
30.0		0.87		2.74		4.13
40.0		0.86		2.72		4.11
50.0		0.89		2.74		4.11
60.0		0.88		2.69		4.12
70.0		0.89		2.66		4.11
80.0		0.87		2.65		4.08
90.0		0.89		2.62		4.09
100.0		0.88		2.64		4.11
108.0		0.85		2.58		4.12
115.0		0.89		2.60		4.05
120.0		0.88		2.60		4.07
123.0		0.87		2.56		4.06
125.5		0.85		2.54		3.97
127.5		0.84		2.46		3.94
129.0		0.79		2.29		3.82

TABLE II.—EXPERIMENTAL LAMP No. 2.

Length of luminous column L = 82 cm. Average diameter of tube inside d_{ti} = 2.30 cm. Average diameter of tube outside d_{to} = 2.52 cm.

λ cm.		J_λ Intern. candles r. per cm.		J_λ Intern. candles r. per cm.		J_λ Intern. candles r. per cm.
	i = 1.50 amp. *e* = 63.0 volts *t* = 21.5 centgr.		*i* = 2.50 amp. *e* = 56.6 volts *t* = 17 centigr.		*i* = 4.20 amp. *e* = 55.4 volts *t* = 19 centigr.	
1.0		0.44		1.26		2.74
2.5		0.79		2.33		3.78
4.5		0.96		2.72		4.09
7.5		1.01		2.79		4.11
11.0		1.01		2.82		4.17
16.0		1.01		2.77		4.17
24.0		1.01		2.81		4.17
34.0		1.02		2.81		4.20
44.0		1.00		2.77		4.18
54.0		1.04		2.72		4.17
62.0		0.97		2.73		4.18
67.0		0.97		2.72		4.17
72.0		0.96		2.74		4.17
75.0		0.96		2.72		4.12
77.5		0.90		2.72		4.11
79.5		0.86		2.62		4.00
81.0		0.79		2.33		3.58

TABLE III.—EXPERIMENTAL LAMP No. 3.

Length of luminous column L = 36 cm. Average diameter of tube inside d_{ti} = 2.26 cm. Average diameter of tube d_{to} = 2.48 cm.

λ cm.		J_λ Intern. candles r. per cm.		J_λ Intern. candles r. per cm.		J_λ Intern. candles r. per cm.
	i = 1.50 amp. *e* = 34.0 volts *t* = 19 centigr.		*i* = 2.50 amp. *e* = 31.0 volts *t* = 21 centigr.		*i* = 4.20 amp. *e* = 30.1 volts *t* = 22 centigr.	
1.0		0.47		1.45		3.26
2.5		0.82		2.34		4.05
4.5		1.02		2.74		4.35
8.0		1.04		2.82		4.39
12.0		1.03		2.85		4.40
16.0		0.99		2.84		4.40
21.0		1.02		2.86		4.39
26.0		0.99		2.84		4.39
29.0		0.99		2.82		4.41
31.5		0.98		2.82		4.40
33.5		0.95		2.72		4.32
35.0		0.81		2.49		4.07

TABLE IV.

Length of luminous column L cm.	36			82			130		
Current intensity *i* amp.	1.5	2 5	4 2	1.5	2.5	4.2	1.5	2.5	4.2
$J\lambda_1$ Int. c. r. p. cm..	1.007	2.851	4.402	1.014	2.773	4.188	0.887	2.685	4.104
$J\lambda_2$ Int. c. r. p. cm..	0.950	2.771	4.343	0.981	2.743	4.141	0.871	2.651	4.074
$\frac{J\lambda_2}{J^{\lambda 8}}$	0.944	0.972	0.986	0.967	0.989	0 989	0.982	0.987	0.991

8. The Light Intensity and Specific Consumption Obtainable with Mercury-Vapor Lamps.

In order to determine the relation the light intensity and economy bear to the tube diameter, six similar mercury-vapor

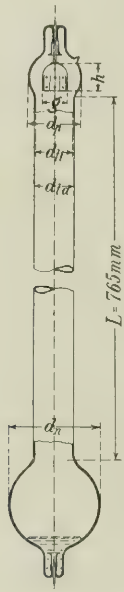


Fig. 9.—Type of experimental lamps Nos. 4 to 9.

lamps of equal length of luminous column but different tube diameter were made, and a center section of the luminous column of each one was subjected to a photometric observation

under simultaneous reading of current intensity and potential difference between electrodes. The experimental lamps had the shape shown in Fig. 9, and were designed for direct current, vertical running position, with anodes of iron and unpainted spherical cooling chambers on both terminals. The dimensions of the positive electrodes were kept so that all lamps at normal current had about the same current density at the anode; the outside diameter of the negative chamber had such a ratio to the inner tube diameter that the lamps operated under nearly uniform temperature conditions. The characteristics in Fig. 10a prove that these proportions were struck upon as correctly as possible without excessive costs.

The investigations were made with the above described photometer and standard lamp; the slot width was $c = f = 50$ mm. (2.0 in.). The experimental tube was fastened in front of the screen S_2, Fig. 6, its center being coincident with the center of the slot. The photometric readings were not taken until perfectly stationary conditions were reached which consumed from ½ to ¾ hour after every change. The current intensity, both, of the standard and the experimental lamp, was carefully regulated by a second observer, and was changed step by step, beginning with the minimum current on which the arc could just be maintained with plenty of self induction in the circuit, up to the maximum current intensity where the positive electrode started to grow red-hot and the anode drop increased rapidly, beyond which point a continuous running of the lamp was impossible. The photometric readings could be taken very exactly.

The results are contained in the Tables V to X, the respective calculations are performed with a 20-in. slide-rule. The letters signifying the dimensions of the different experimental lamps refer to Fig. 9: "i" designates the current intensity of the arc, "e" the potential difference between the electrodes of the lamp, "t" the mean room temperature during the test, J the measured radial light intensity of a center streak of the luminous column of the lamp investigated based on a unit of 2.66 international candles r. p. cm. of the standard lamp (see above); $w = e\,i$ is the watt consumption excluding the series resistance and $w = \dfrac{ei}{0.98\,L\,J}$ the specific watt consumption referred to

the entire lamp and taking into account the factor 0.98 of the previous chapter.

In regard to the value e for the *highest* current intensity of every lamp it may be set forth that these are the only observations of each series that are not quite correct, because the temperature of the positive electrodes under that overload became so high that the lamp voltage was very unstable.

TABLE V.—EXPERIMENTAL LAMP NO. 4.

Dimensions of tube: column L = 30 in. = 765 mm. Tube diameter inside, $d_{ti} = 8.6$ mm. Tube diameter outside, $d_{to} = 9.9$ mm. Diameter of the positive cooling chamber, $d_p = 19.2$ mm. Diameter of the negative cooling chamber, $d_n = 22.5$ mm. Dimensions of the positive electrode (see Fig. 9): g = 9 mm., $h = 11$ mm. Mean room temperature $t = 27$ centigr.

i Amp.	e Volts	J Inter. candles radial per cm.	ie Watts	$w = \frac{ie}{0.98JL}$ Watts per candle
0.60	111.4	1.56_0	66.8	0.56_8
0.80	109.6	1.75_9	87.6	0.66_5
0.90	118.8	1.80_0	106.9	0.79_2
1.00	123.0	1.90_4	123.0	0.86_2
1.15	151.*	2.15_4	170.0	1.07_6

* Uncertain.

TABLE VI.—EXPERIMENTAL LAMP NO. 5.

Dimensions of tube: L = 765 mm., $d_{ti} = 15.6$ mm., $d_{to} = 17.6$ mm., $d_p = 25.4$ mm., $d_n = 40.5$ mm. Dimensions of the positive electrode: $g = 13$ mm., $h = 14$ mm. $t = 28$ centigr.

i Amp.	e volts	J Inter. candles radial per cm.	ei Watts	$w = \frac{ei}{0.98\,L\,J}$ Watts per candle
0.70	76.5	0.77_9	53.5	0.91_7
0.90	74.2	1.16_4	66.8	0.76_6
1.20	70.0	2.05_0	84.0	0.54_7
1.50	66.8	2.55_6	100.2	0.52_3
1.80	66.5	2.81_4	119.6	0.56_7
2.10	68.5	3.10_9	143.8	0.61_7
2.40	73.0*	3.31_7	175.1	0.70_5
2.70	88.5*	3.60_9	237.4	0.87_8

* Uncertain.

TABLE VII.—Experimental Lamp No. 6.

Dimensions of tube: $L = 765$ mm., $d_{ti} = 25.0$ mm., $d_{to} = 27.1$ mm., $d_p = 34.4$ mm., $d_n = 63.4$ mm. Dimensions of positive electrode: $g = 17$ mm., $h = 19$ mm. $t = 25$ centigr.

i Amp.	e Volts	J Inter. candles radial per cm.	$e\,i$ Watts	$w = \frac{i\,e}{0.98\,L\,J}$ Watts per candle
0.75	58.6	0.191	43.9	3,070
1.15	56.1	0.626	64.5	1.375
1.50	54.5	0.932	81.7	1.170
1.90	52.3	1.687	99.4	0.786
2.30	50.5	2.352	116.1	0.659
2.70	48.6	3.029	131.1	0.578
3.10	47.0	3.753	145.6	0.518
3.50	45.6	4.05	159.4	0.525
3.90	46.3	4.19	180.6	0.575
4.30	51.2	4.27	220.0	0.688
4.70	68.*	4.43	319.4	0.964

* Uncertain

TABLE VIII.—Experimental Lamp No. 7.

Dimensions of tube: $L = 765$ mm., $d_{ti} = 35.0$ mm., $d_{to} = 37.5$ mm., $d_p = 48.0$ mm., $d_n = 89.0$ mm. Dimensions of positive electrode: $g = 24$ mm., $h = 25$ mm. $t = 23$ centigr.

i Amp.	e Volts	J Inter. candles radial per cm.	$e\,i$ Watts	$w = \frac{e\,i}{0.98\,L\,J}$ Watts per candle
0.85	49.2	0.194	41.8	2.870
1.20	49.0	0.341	58.8	2.302
1.70	48.0	0.598	81.6	1.820
2.20	46.2	1.017	101.6	1.332
2.70	44.4	1.651	119.9	0.969
3.20	43.2	2.304	138.2	0.801
3.70	42.0	3.042	155.4	0.682
4.20	40.6	3.753	170.4	0.607
4.70	39.3	4.38	184.6	0.563
5.20	38.6	4.86	200.8	0.55[illegible]
5.70	38.6	5.11	219.9	0.575
6.20	41.0	5.20	254.0	0.652
6.70	50.*	5.12	335.0	0.874
6.90	60.*	4.87	414.0	1.135

* Uncertain.

TABLE IX.—EXPERIMENTAL LAMP NO. 8.

Dimensions of tube: L = 765 mm., d_{ti} = 45.8 mm., d_{to} = 47.6 mm., d_p = 61.6 mm., d_n = 116.0 mm. Dimensions of positive electrode: g = 31 mm., h = 24 mm. t = 22 centigr.

i Amp.	e Volts	J Inter. candles radial per cm.	$e\,i$ Watts	$w = \frac{e\,i}{0.98\,L\,J}$ Watts per candle
1.20	41.8	0.167	50.2	4.010
1.80	41.7	0.344	75.0	2.916
2.50	41.5	0.613	103.7	2.258
3.20	40.7	1.090	130.2	1.594
4.00	39.0	1.843	156.0	1.130
4.90	37.5	2.809	183.6	0.873
5.80	36.5	3.762	211.4	0.751
6.80	34.7	5.18	235.9	0.608
7.80	33.8	6.06	263.3	0.580
8.80	33.3	6.78	292.8	0.577
9.80	34.0	7.18	332.9	0 620
10.40	37.6	7.27	390.8	0.718
10.70	49.*	7.09	524.0	0.987

* Uncertain.

TABLE X.—EXPERIMENTAL LAMP NO. 9.

Dimensions of tube: L = 765 mm., d_{ti} = 61.5 mm., d_{to} = 66.0 mm., d_p = 80.8 mm., d_n = 152.5 mm. Dimensions of positive electrode: g = 38 mm., h = 35 mm. t = 27 centigr.

i Amp.	e Volts	J Inter. candles radial per cm.	$e\,i$ Watts	$w = \frac{e\,i}{0.98\,L\,J}$ Watts per candle
1.50	36.5	0.196	54.7	3.727
2.30	36.5	0.374	84.0	2.995
3.20	36.5	0.713	116.7	2,188
4.10	35.7	1.206	146.4	1.620
5.10	34.5	1.855	175.8	1.266
6.20	33.1	2.772	205.0	0.988
7.40	32.1	3.843	237.3	0.825
8.70	31.0	5.10	269.6	0.707
10.00	30.0	6.23	300.0	0.644
11.30	29.2	7.23	330.0	0.609
12.40	29.0	7.86	359.5	0.610
13.00	29.0	8.10	376.8	0.621
14.00	29.5	8.41	413.0	0.655
15.00	30.2	8.56	453.0	0.707
16.00	34.*	8.31	544.0	0.874

* Uncertain.

For the sake of greater lucidity the values c and w of the above tables are plotted as functions of i in the Fig. 10a and b, each curve being marked with the number of the corresponding experimental tube. First, one will discover that, observation errors excepted, all lamps show the least specific watt consumption at the lowest point of their characteristic, that is at the minimum terminal voltage. As this point of the characteristic not only signifies the most favorable vapor pressure but also is remarkable for the steadiness of the mercury arc, the coördinate current intensity is here called the *normal current of a mercury-vapor lamp* and is denoted by i_n.

A superficial contemplation of the curves in Fig. 10b might lead to the wrong conclusion that the specific consumption obtained with mercury-vapor lamps was almost independent of the tube diameter and, without taking into consideration the series resistance, amounted to about 0.5 watt per C. r. This is not the case. As is well known, the potential difference consumed in a (mercury)-arc can be divided in two parts, each one distinguished from the other in a physical and technical sense: The electrode fall of potential, Δ_c, Δ_a, and the potential drop in the luminous column. Within the limits actually to be taken into consideration, the cathode fall of potential, Δ_c, of the mercury-arc is, almost invariable and equal to 5.3 volts. The anode fall, Δ_a is dependent upon the material of the electrode, the current density, the temperature and vapor density at the positive electrode. The potential gradient of the luminous column $\frac{d\,V}{d\,\lambda}$ is constant along the entire column and is dependent only upon the vapor density or local temperature and upon the ratio of the number of conductive mercury particles to the number of neutral vapor (or gas) particles per unit volume. Let L signify the length of the luminous column, approximately equal to the electrode distance minus the length of dark cathode space, then the potential difference between the electrodes of a mercury-vapor lamp can also be expressed by

$$e = \Delta_c + \Delta_a + \frac{d\,V}{d\,\lambda} \,.\, L = f(i), \tag{57}$$

or for a certain lamp and a determined current intensity

$$e = A + B \,.\, L, \tag{58}$$

where A and B mean constants depending upon the current density and the heat radiation conditions.

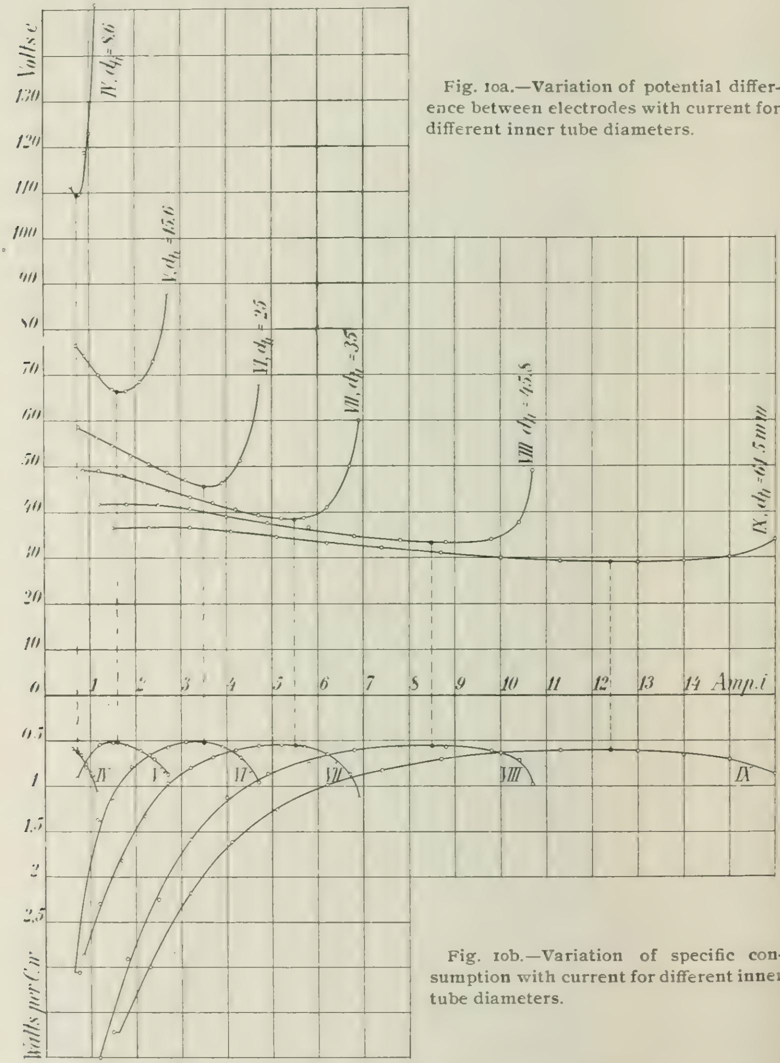


Fig. 10a.—Variation of potential difference between electrodes with current for different inner tube diameters.

Fig. 10b.—Variation of specific consumption with current for different inner tube diameters.

Hence, of the total energy, consumed in the arc, only the part of $\frac{B \cdot L}{e}$. 100 per cent., belonging to the luminous column, is

directly utilized for generation of light, while the rest of $\frac{A}{e}$ 100 per cent. is converted into heat at the electrodes, thus not only contributing nothing to the light radiation, but moreover even decreasing the efficiency of the light column by about 2 per cent. by heating it, as mentioned above.

Neglecting the energy wasted in the series resistance, the theoretical efficiency of a mercury-vapor lamp is therefore

$$\eta_t = \frac{B \cdot L}{A + B \cdot L} \tag{59}$$

If the current intensity and all lamp dimensions with the exception of the length of the tube be assumed constant, then with increasing L, η_t will continuously approach unity. The characteristics of Fig. 10a prove further that B decreases with increasing tube diameter, whilst A is almost independent of the tube diameter, provided that the current density and the temperature of the anode are not changed. Hence, when L is kept constant and the tube diameter is increased as with the experimental lamps Nos. 4 to 9, η_t will always decrease; that is the specific consumption would be found becoming always smaller. In order to answer correctly the question for the maximum obtainable economy one must subtract the energy converted into heat on the electrodes, and take into account only that part consumed in the luminous column; that is, as theoretical efficiency is to be formulated the limit which may be called *the ideal efficiency of the mercury-vapor lamp*:

$$\eta_i = \lim. \left[\frac{B \cdot L}{A + B \cdot L}\right]_{L = \infty} . \tag{60}$$

Certainly one must not forget that this efficiency has a purely theoretical meaning; for in order actually to reach η_i with large tube diameters, one would arrive at tubes so unproportionately long that the lamp would not be practical.

At normal current the electrode fall of potential of a mercury-vapor lamp of the type shown in Figs. 7 and 9 with iron anode, is 11.9 volts including the little drop in the negative cooling

chamber. The ideal specific watt consumption of the lamps Nos. 4 to 9 would, therefore, be

$$w_i = \frac{e - 11.9}{e} \cdot w.$$

In calculating, in this way, the magnitude of w_i for the corresponding normal currents i_n for every one of the six experimental

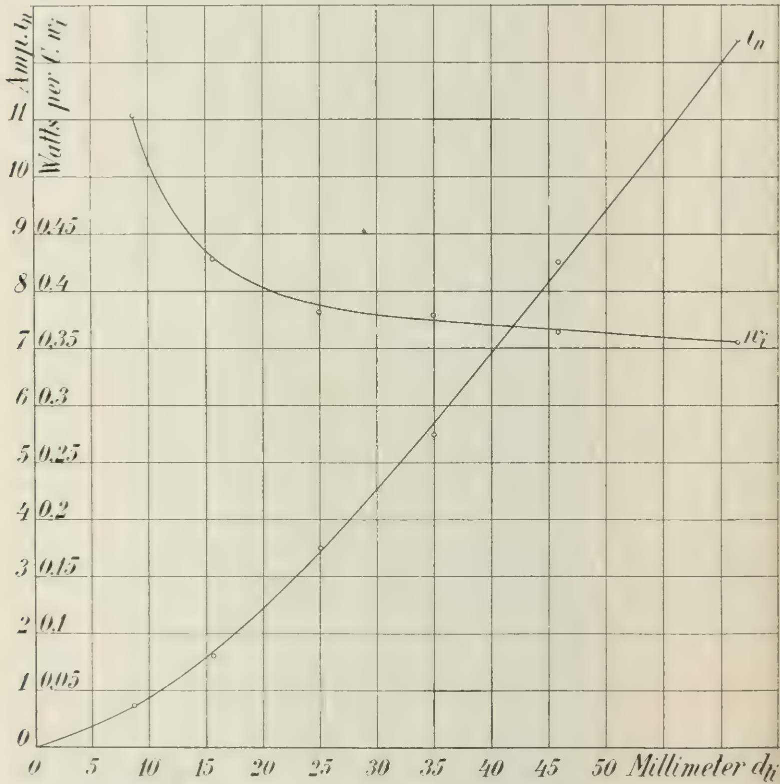


Fig. 11.—Variation of the normal current and specific consumption with the inner diameter of the tube.

tubes from tables V to X and the curves of Fig. 10a and 10b and plotting w_i and i_n as functions of the inner tube diameter, the curves of Fig. 11 are obtained.

To summarize the deductions of this chapter one now may say:

For the estimation of the minimum specific consumption attainable with a mercury-vapor lamp, two quantities are important: The normal current intensity of the lamp, i_n, and the ideal efficiency, η_i. The difference of the potential between the lamp electrodes, being expressed by the relation

$$e = f(i) = A + BL.$$

i_n and η_i are defined by

$$\frac{d f(i_n)}{di_{(n)}} = 0, \quad \eta_i = lim. \left[\frac{B L}{f(i)}\right]_{L - \infty} .$$

The lamp reaches the best specific consumption at the normal current intensity.

The smallest specific watt consumption theoretically obtainable, $w_i = \eta_i \cdot \frac{i f(i)}{0.98 L J}$, decreases with increasing tube diameter.

9. The Alternating Current Mercury-Vapor Lamp.

In addition to the above experiments referring exclusively to lamps for direct current, the mercury-vapor lamp for alternating current may here be submitted to a short investigation. As is well known, this type lamp operates on the principle of the mercury-vapor rectifier, the energy of the converted electric current being consumed in an extended luminous column of the rectifier bulb itself and there transformed into light radiation. It does not seem desirable to enter here into the details of the complicated but well analysable phenomena in this type lamp, but merely to ascertain if its light radiation is dependent upon the magnitude of the fluctuations of the rectified current and to determine what the relation of its light intensity is compared with that of a direct current lamp.

For the experiments a special mercury-vapor tube was so constructed that it could be run as well on direct as on alternating current with however great current pulsations. This tube had two main iron anodes a_1, a_2 Fig. 12, and a mercury cathode c.

For maintaining the intensive ionization of the cathode, independently of intensity and pulsations of the rectified current, an auxiliary anode a_3 of mercury was provided and between a_3 —c an arc of 1.0 amp. and was maintained from a direct-current source.

This lamp tube was fastened vertical in clamps before the screen S_2, Fig. 6, of the above described photometer with the center of the slot in the half height of the luminous column; as a standard, use was made of the above described short mercury-

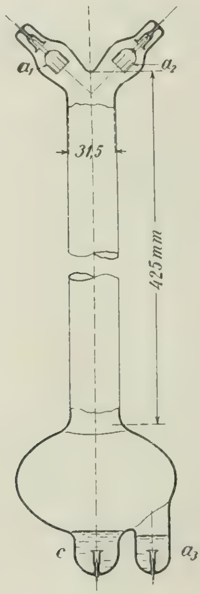


Fig. 12.—Type of experimental lamp No. 10.

vapor lamp, the slot widths being $c = f = 50$ mm. (2 in.).

The rest of the experimental arrangement may be perceived from Fig. 13. Therein S_w signifies a three-pole, double-throw switch connecting the lamp to the direct-current source in position I and to the alternating-current source in position II: T is an auto-transformer the two terminals of which were connected to the main positives a_1, a_2 whilst the neutral point, as usual, led to the cathode c. The voltage of the supply to T was regulated by means of a variable-ratio transformer and a small resistance.

For regulation of the direct current the resistance R_2 was used. When the lamp was operated on direct current there was the danger that, when the positives a_1, a_2 became unequally heated, the current would pass only over one of them and thereby render the conditions different from what they would have been on alternating current, on account of the different current densities at the anode. To prevent this an equalizing resistance, R_1, was connected to the main positives, so that each electrode got $\frac{1}{2}$ R_1 and an eventual overloading of one electrode was automatically balanced by the drop of potential in the two resistance halves.

When a lamp such as the above is run on alternating current

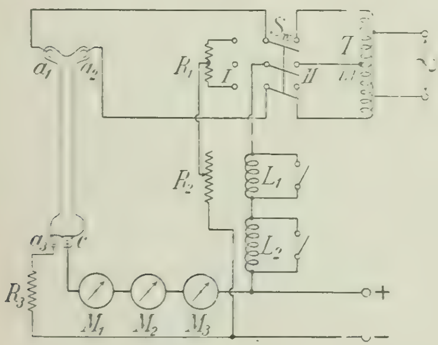


Fig. 13.—Diagram of experimental arrangement.

the magnitude of the pulsations of the rectified current (which had to be varied) is determined first by the inductance before the cathode, then by the inductance of the other circuits and the wave shape of the primary alternating current. The two latter were almost constant, but the inductance in series with the cathode was variable: for, it consisted of the invariable inductances of the ammeters M_1, M_2 (Fig. 13) and of the two self induction coils L_1 L_2 each to be singly short-circuited.

A perfect study of the course of the rectified current would have been achievable by taking its wave shape. As instruments for this purpose were not available the following method was used for ascertaining the magnitude of the current fluctuations: In series with the cathode were connected three ammeters each of a different type: a direct-current ammeter, M_1

of the type with a movable spool in the field of a permanent magnet, a hot wire ammeter M_2 and ammeter M_3 of the induction type. The ammeter M_1 showed the mean current intensity

$$i_1 = \frac{1}{T}\int_o^T i\,dt$$

(Fig. 14) of the pulsating current. Ammeter M_2 measured the mean effective current value

$$i_2 = \sqrt{\frac{1}{T}\int_o^T i^2 dt},$$

whilst M_3 indicated only the alternating current wave superposed

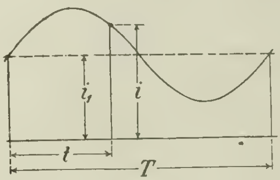


Fig. 14 —Pulsating current.

upon the direct current, that is the mean effective value of the pulsations

$$i_3 = \sqrt{\frac{1}{T}\int_o^T (i - i_1)^2 dt.}$$

For a wave of pure sine shape there would have been the well-known relation,

$$i_3^2 = i_2^2 - i_1^2.$$

For performing the measurements the experimental lamp was started on the lowest direct current intensity and the current was kept at this adjustment until it became perfectly stationary, then the photometer readings were taken. Later the switch S_x was connected to alternating current with the largest self induction in the circuit of the cathode, that is, with adjustment for smallest pulsations of the rectified current. The alternating current was regulated by the variable-ratio transformer to exactly the same value i_1 as read on M_1 formerly and kept at this current intensity

for ten minutes; the lamp now being warm enough from the previous observation, the stationary current conditions were reached and the photometer reading could be taken. Subsequently the current pulsations were increased by short-circuiting the larger one of the self induction spools; by properly regulating the alternating current, i_1 was again brought to the same value as before and, after ten minutes, the photometric observations were made again. Finally by short-circuiting both coils L_1, L_2, the fluctuations of the rectified current were raised to the highest obtainable magnitude, and the photometric tests were taken again at the same value of i_1. One series of observations being thus completed the lamp was switched over to direct current, i_1 was increased by changing the resistance R_2 and the observations were repeated in the same sequence.

The data obtained are shown in Table XI under the former symbols. J_d signifies the light intensity of the experimental lamp on *direct* current in C. r. per cm. of the luminous column, J_{a1}, J_{a2}, J_{a3} are the light intensities of the same lamp on *alternating* current with smallest, medium and greatest current-pulsations; e stands for the voltage between the terminals a_1 or a_2 and c when the lamp ran on direct current. Readings of the lamp voltage with alternating current were not taken because with mercury arc rectifiers such readings are worthless unless made with a synchronous contact apparatus and no such device was at hand.

The arc could not steadily be maintained on alternating current at the very small current intensities and without sufficient self induction in the circuit of the cathode; for, although the cathode had been kept ionized by the auxiliary arc a_3—c, the electrode distance a_1 c was still too great for the low alternating voltage impressed upon the electrodes.

In comparing the values of the light intensities at a certain mean current intensity i_1 one will find a striking conformity between them, and will now understand why it was just the same *mean current* i_1, that each observation series was based on. The comparison can be made plainer by means of the percentage difference, $\frac{J_d - J_a}{J_d} \cdot 100$ contained in the table. It is true that, even when the observation errors are taken into consideration,

TABLE XI. EXPERIMENTAL LAMP NO. 10.

L = 425 mm., d_n = 31.5 mm., t = 32 centigr. Current intensity of auxiliary arc a_3–c = 1.0 amp. direct current.

i_1 Amp.	Lamp on direct current: e Volts	Lamp on direct current: Jd J. c. r. p. cm	Alternating current with maximum inductance: i_2 Amp. m. r. s.	i_3 Amp. m. r. s.	Ja_1 J. c. r. p. cm.	$\frac{Jd-Ja_1}{Jd}\cdot 100$ Per cent.	Alternating current with medium inductance: i_2 Amp. m. r. s.	i_3 Amp. m. r. s.	Ja_2 J. c. r. p. cm.	$\frac{Jd-Ja_2}{Jd}\cdot 100$	Alternating current with smallest inductance: i_2 Amp. m. r. s.	i_3 Amp. m. r. s.	Ja_3 J. c. r. p. cm.	$\frac{Jd-Ja_3}{Jd}\cdot 100$ Per cent.	Remarks
0.30	39.2	0.067	0.31*	0	0.067	0.00	—†	—	—	—	—†	—	—	—	* Lamp unsteady.
0.60	38.0	0.189	0.62	0	0.195	−3.17	—†	—	—	—	—†	—	—	—	† Arc between main electrodes could not be maintained.
1.00	34.0	0.530	1.03	0	0.523	+1.32	1.10*	0.53	0.532	0 38	—†	—	—	—	
1.50	32.9	1.026	1.51	very small	1.036	−0.97	1.59	0.59	1.035	−0.88	—†	—	—	—	
2.00	32.0	1.547	2.00	very small	1.559	−0.72	2.14	0.62	1.583	−2.32	—†	—	—	—	
2.60	31.0	2.250	2.62	very small	2.201	+2.18	2.71	0.65	2.232	+0.80	2.99	1.65	2.250	0.00	
3.20	30.3	2.959	3.20	very small	2.900	+1.99	3.34	0.66	2.880	+2.67	3.62	1.72	2.867	+3.11	
3.80	29.9	3.461	3.85	very small	3.450	+0.32	3 95	0.67	3.447	+0.40	4.22	1.84	3.391	+2.02	
4.40	29.5	3.913	4.42	0.04	3.913	0.00	4.55	0.75	3.880	+0.84	4.81	2.02	3.834	+2.02	
5.00	29.9	4.17	5.01	0.06	4.17	0.00	5.14	0.80	4.13	+0.96	5.30	2.14	4.09	+1.92	
						Average +0.095				Average +0.261				Average +1.81	

an increase of those differences with increasing fluctuations is not to be denied; for, as the table shows, the average deviation $\frac{J_{:} - J_{2}}{J_{i}}$ was the smallest at the smallest current pulsations, namely only $+0.095$; it increased with medium inductance to $+0.261$ and reached the maximum value of $+1.81$ at the greatest current fluctuations. However, these discrepancies are so small that they practically can be neglected, especially considering that the light would flicker very disagreeably even with a damping of the fluctuations as in the medium case (J_2), and that an alternating-current mercury-vapor lamp with pulsations as large as the greatest here used, would by no means be practicable.

The investigation recorded above, therefore, show the following: *The light intensity of an alternating current mercury-vapor lamp is the same as that of a direct current lamp at the same average current intensity at the cathode, provided the two lamps have equal tube dimensions, equal current densities at the anode and the same heat radiating conditions. The results recorded in the previous paragraph are therefore true also for the alternating current lamps.*

DISCUSSION.

Mr. Bassett Jones, Jr. (Communicated):—One point in connection with Dr. Pole's paper needs particular emphasis; the flux from a light source of any form and shape whatsoever is absolutely independent of the form and shape of the surface enclosing the source and over which the flux is measured either by calculation or by measurement.

Whether "the proposition of *computing* the total luminous flux of a light-line is an indefinite problem," or not, is still an open question. It may be indefinite and, in fact, must be indefinite, if absolute generality is given to the equations. Dr. Pole attempts to deduce an expression for total luminous flux over a surface having the general equation $F(x, y, z) = O$. The result itself must of, course, be quite as general and just as indeterminate as the premises. According to Dr. Pole's method he is perfectly justified in drawing the conclusion that the total

luminous flux computed over an infinite cylindrical or a spherical surface is the only flux independent of the surface chosen in the family of surfaces. But it should be remembered that this is the only constant flux *obtainable by computation* using this method. The variable is in the equation and not in the flux.

Any other conclusion would of course be a direct refutation of the law of conservation of energy—a law with which few physicists care to meddle.

S. W. Ashe (Communicated) :—This excellent paper by Dr. Pole will indicate how difficult it has been in the past to obtain a correct numerical value for the luminous efficiency of the mercury vapor tube. Methods used in the past have depended largely upon the process of elimination. For instance, according to Dr. Ives, it is necessary to photometer a mercury vapor tube at a distance equal to at least five times its length in order to eliminate errors from considering it as a point light source. It is also known from the measurements of Mr. Preston Millar and others, that is the tube is photometered at too great a distance serious errors are introduced, due to the Purkinje effect. The logical method, therefore, has been to measure the tube at a distance of about 20 ft. obtaining the mean spherical candle-power in two or three planes, and from these to obtain the average value of the mean spherical candle-power. Multiplying these values by 4π gives the total lumens.

According to my interpretation of equation No. 23 of Dr. Pole's paper, this quantity or total lumens, obtained in the manner previously indicated, is a variable quantity; for the nearer one gets to the tube the greater the total lumens become. I can hardly conceive of such a condition. One would assume on the contrary, if the tube be considered as a point light source in making calculations, that the nearer one comes to the tube the smaller will the measured values become. Such measurements which I have made with the luminometer check this statement, although the variations from the theoretical curve are not so great as one would be led to expect, except where one is quite near the tube.

I may be wrong in interpreting Dr. Pole's findings, although I feel that the mathematical computations are undoubtedly exact. The trouble must lie therefore in the form of unit which Dr. Pole

describes on the first page of his paper represented by the quantity of "J," or the candles per centimeter normal to the axes. While the selection of an arbitrary unit is justifiable in some respects, the equations which Dr. Pole has arrived at seem to indicate that the mathematical computations are not conclusive.

Furthermore Dr. Pole describes a method for photometering the tube, in which is used primary mercury vapor standard that has been aged. I would like to obtain further detail as to the amount of variation in candle-power which occurred during this aging process. In tests which I have made quite a marked falling off in candle-power in the first hundred hours is noted in the mercury vapor tube, and the process of falling off is continuous, so that I should hardly care to employ one as a standard for comparison. It would seem that a much better method, particularly with the direct current tube, would be to use a flicker photometer and check it against a standard incandescent lamp. It is a very easy matter to secure a standard incandescent lamp for such purposes, and a Rood type flicker photometer can be built for about \$25.00, which will practically eliminate color differences, and will be found to be quick and give accurate results. I feel that this method is preferable to that of using as a secondary standard the mercury vapor tube.

Dr. K. Norden (Communicated):—I have studied the photometry of light-lines, and some of the results of my investigations have been published in the Elektrotechnische Zeitschrift in 1907 (No. 31) and 1908 (No. 37) under the title "Beleuchtungsberechnungen fuer Quecksilberdampf-Lampen." I have found it more convenient to introduce trigonometric terms. The formulae which I arrived at are easier on the eye and may be applied more readily. Dr Pole's general equation (No. 13) for the illumination E_1 is given by formula No. 3 of my paper as follows:

$$E = \frac{J}{4a} \cos^2\beta \left[(\sin 2\alpha_1 + \sin 2\alpha_2) + (2\alpha_1 + 2\alpha_2)\right]$$

and in the special case of 17 it becomes

$$(3b) \quad E_0 = \frac{J}{2a} (\sin 2\alpha_0 + 2\alpha_0),$$

where $2\alpha_0$ is the angle, under which the light-line is seen from point P.

From $3b$ is easily derived the true light intensity J. L. of the lamp, that is, the light intensity for an infinite distance of the photometer screen, where all rays entering the photometer can practically be considered as parallel. In the practical test, the readings must be taken at a sufficient distance, or must be reduced to infinite distance by means of the formula.

Below will be found an excerpt from my paper in which some practical tests of this kind were given. The figures show that a distance of about 2.5 times the length of the lamp was sufficient for practical purposes to get constant readings, but each value taken at any distance could be reduced by applying the formula.

$$\text{Light intensity} = \text{J.L} = \frac{E_0.4.L.a}{\sin 2a_0 + 2a_0},$$

derived from $3b$.

The average of the calculated true light intensities (II) is 715; the maximum difference is only 2.5 per cent., while the measured intensities differ up to 34 per cent. It seems to me that the photometry of light-lines is fully given therein.

No. of test	Distance from lamp to photometer	I Apparent light intensity measured by applying the law of inverse squares	II True light intensity calculated from the values of series I
1	2.85 m.	714.8 HK	733.0 HK
4	1.79 m.	664.4 HK	707.0 HK
6	1.05 m.	608.1 HK	716.6 HK
8	0.60 m.	471.6 HK	704.4 HK

A. S. McAllister (Communicated) :—The author has treated the mercury vapor lamp as a mathematical "straight-line" source of light. A mathematical line can be considered either as made up of an infinite number of points or as a cylinder of zero diameter, or as a plane surface of zero width. In assuming that the so-called "cosine law" is applicable to his problem, the author tacitly adopts as a mathematical line a cylindrical surface of infinitesimal diameter. The fact of the matter is that vapor-tube lamps are neither point nor surface sources but are volume sources of light, and can more properly be considered as point-line" sources than as "surface-line" sources. By reason of the mechanical arrangement of the vapor-tube lamp, when it is treated as a "point-line" source correction must be made for the light intercepted by the terminals and absorbed or redirected by

the glass envelope and to some extent by the vapor itself. The error involved in treating the lamps as a "surface-line" source are such as to tend to compensate for the presence of the terminals and the glass envelope, and hence this treatment may be approximately in accord with the relations observed photometrically. Even its very close agreement with the photometric observations would not show, however, that the source is a "surface-line" rather than a "point-line" source.

The first half (26 pages) of the paper are taken up by a demonstration of the relation existing between the author's so-called "radial candle-power" and the total flux emitted by a linear source having an output of a certain number of such candles per unit length. The author's demonstrations are unnecessarily complicated, as will be appreciated from the simple demonstrations given below.

Referring to Fig. 1 and treating the source as a "surface-line," the flux on an elementary concentric ring having an area

Figs. 1 and 2.—Illumination produced by "surface-line" and "point-line" sources.

$2\pi\, ndx$ produced by the elementary light-line $d\,l$ having a "radial candle-power" per unit length of c is

$$d\psi = 2\pi n dx (cdl)\ \frac{\sin^2 \alpha}{r^2}\ . \qquad (1)$$

From trigonometric relations

$$x = n \tan \alpha, \text{ and } dx = \frac{n}{\cos^2 \alpha} d\alpha \qquad (2)$$

$$r^2 = \frac{n^2}{\cos^2 \alpha} \qquad (3)$$

substituting (2) and (3) in (1)

$$d\psi = 2\pi (cdl) \sin^2 \alpha d\alpha \qquad (4)$$

The total flux produced by the elementary light-line on the inner surface of a cylinder of infinite length is

$$\psi = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} 2\pi(cdl)\sin^2\alpha d\alpha \tag{5}$$

$$= 2\pi(cdl) \Big[\tfrac{1}{2}\alpha - \sin\alpha\cos\alpha \Big]_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} \tag{6}$$

for a length of light-line l the total flux produced on the interior of the cylinder of infinite length is

$$\psi_l = \pi^2 cl. \tag{7}$$

This value is identical with the value obtained by the author. It is to be noted that the value of ϕ_l is independent of n; this means that the total flux is independent of the diameter of the enclosing cylinder, as one should predict at once from the well established law of conservation.

In the case of a light-line of infinite length surrounded by a concentric cylinder of finite length, the solution is quite similar to the above. Referring again to Fig. 1, the elementary light flux density at a point P on a plane parallel to the light line, and perpendicular to the light rays at this point, produced by the elementary length dl of the light line, is

$$d\beta = \frac{cdl}{r^2}\sin^2\alpha \tag{8}$$

$$l = n\tan\alpha \tag{9}$$

$$dl = \frac{n}{\cos^2\alpha}d\alpha \tag{10}$$

$$r^2 = \frac{n^2}{\cos^2\alpha}. \tag{11}$$

Hence

$$d\beta = \frac{c}{n}\sin^2\alpha. \tag{12}$$

The total light flux density at point P produced by a light-line of infinite length is

$$\beta = \frac{c}{n}\Bigg|_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \left(\frac{\alpha}{2} - \sin\alpha\cos\alpha\right) = \frac{\pi}{2}\,\frac{c}{n}.$$

On a concentric ring surrounding the light-line at P, and having a radius n and a length l the total flux would be

$$\psi_l = 2\pi n l\beta = \pi^2 cl. \tag{13}$$

It will be observed from equations (13) and (7) that the value for the flux per unit length of cylinder enclosing an infinite light-line is identical with the value for the flux per unit length of light-line within a cylinder of infinite length, the value in each case being independent of the diameter of the cylinder. It can easily be shown that the same value is obtained when the light-line is placed within a spherical enclosure or an enclosure of any shape or size whatsoever, the relation being as fundamental as is the law of conservation.

If the line source produced c "mean spherical candle-power" rather than c "radial candle" per unit length, the total flux for the length l would be $4\pi cl$ instead of $\pi^2 cl$. Hence the "spherical reduction" factor for the "radial candle-power" of a "surface-line" source is

$$\pi^2 \div 4\pi = 0.7854.$$

The above relations apply specifically to "surface-line" sources. Referring to Fig. 2, the following relations apply to "point-line" sources.

At any point P at a radial distance of n from the line-source the elementary light flux density $d\psi_n$ produced by the elementary line-source length dl on a plane parallel to the light-line at a distance of r from the point P is

$$d\beta = \frac{cdl}{r^2}\cos\alpha \tag{14}$$

$$l = n\tan\alpha \tag{15}$$

$$dl = n\,\frac{d\alpha}{\cos^2\alpha} \tag{16}$$

$$r^2 = \frac{n^2}{\cos^2\alpha} \tag{17}$$

$$d\beta = \frac{c}{n} \cos \alpha \, d\alpha.$$

For a length of line l the flux density at point P is

$$\beta = \frac{c}{n} \sin \alpha. \tag{18}$$

For a light-line of infinite length to the right and to the left the flux density at point P would be

$$\beta_l = \frac{2c}{n}. \tag{19}$$

From equation (18) it will be noted that the light flux density at any point on any plane parallel to the "point-line" source produced by a finite length of such source, measured from the position on the line perpendicular to the point under consideration, varies directly with the sine of the angle subtended by the source when viewed from this point, the proportionality constant being the quantity $c \div n$. This simple relation allows one to determine the light flux density produced by a "point-line" source by means of a graphical diagram involving merely arcs of circles and straight lines, which anyone familiar with such diagrams can easily construct by use of equation (18). By this means one can readily "explore the whole region" surrounding a "point-line" source of finite length.

Evan J. Edwards (Communicated):—It has not always been clearly understood what was meant when the specific consumption of mercury vapor lamps was given as a certain wattage per candle-power. Since it has been demonstrated by experiment that the cosine law very nearly holds for the mercury vapor tube it seems that the theoretical value of π^2 JL for the total flux as given by Dr. Pole is very close to the actual value. This makes the ratio of radial candle-power to mean spherical $\frac{\pi}{4}$ which is approximately true of most types of incandescent lamps, and very approximately true of the metal filament lamps. The specific consumption of mercury vapor lamps, therefore, should be expressed in terms of watts per radial candle-power for direct comparison with the specific consumption of incandescent

lamps in watts per mean horizontal candle-power. The power should, of course, include the loss in the ballast resistance.

It may be interesting to know that the mercury vapor lamp has a well defined maximum efficiency point and that the diameter of the tube has a part in determining the actual efficiency.

Dr. Pole (Communicated in reply) :—The object of the part of my paper on the computation of the luminous flux, which was to show that the method of calculating the luminous flux by assuming a surface enclosing the source of light and integrating the products of the area of each element of this surface and its illumination, may sometimes involve difficulties. The equations in my paper prove, indeed, that the luminous flux computed in that way may differ from the real flux of light, *i.e.*, the energy radiated into space in form of light which is constant for the respective source of light. I still maintain this conclusion, and cannot admit that, inasmuch as the enclosing surface is in my paper presumed as arbitrarily defined, "the result itself must of course be quite as general and just as indeterminate as the premises." For, an enclosing surface arbitrarily defined will, with *punctiform* sources of light, always give a constant flux of light, *i.e.*, $4\pi \times$ candle-power; and this computed flux will be equal to the flux found either with an integrating photometer or figured from curves of light distribution, if observation errors are not considered. This is the difference between punctiform and extended sources of light. Furthermore, the conclusion in my paper, properly interpreted, need not conflict with the law conservation of energy.

I cannot see in the criticism of Mr. Ashe's any real points why the unit "J" should make the computations not conclusive.

As to the standard used in the investigation, I have stated that the falling off of its candle-power was 1.5 per cent. during 300 hours of its use. The application of the flicker photometer would have been entirely out of place, as it is properly used only where sources of light of different colors have to be compared. The above-mentioned standard was used especially to avoid errors derived from difference in color.

While Mr. Ashe may have found that mercury vapor lamps as

secondary standards for purposes like above researches were far more variable than I have observed, this was in all probability not due to the lamp but to a fault in handling it or to its experimental arrangement.

As to the decrease of light intensity during life of the mercury vapor lamp I hope to be able in a short time to publish a detailed paper on the subject, and it is only for this reason that I do not wish to make a definite statement in this connection.

THE POLAR CURVES OF FINITE LINE AND SURFACE LIGHT SOURCES.[1]

BY BASSETT JONES, JR.

Some time ago the writer had the occasion to take up the study of finite surface light sources, and this study has now extended over a period of about two years. The work was begun by a series of experiments with sources consisting of plane areas of commercial glass arranged so as to emit a fairly uniform specific flux. A large number of polar curves were obtained, so that a fairly accurate idea could be formed of the results that might be expected when any particular type of glassware was used in the construction of such sources for practical use.

In order, however, to determine the actual specific flux required in any particular case to produce certain predetermined values of flux density on the areas or objects to be lighted, it was necessary to carry out a more or less detailed mathematical investigation of the light field produced by finite surface sources. The results of this investigation in the form of formulae for calculating the flux density in various directions at given points in the field have already been presented to the Society and published in the TRANSACTIONS, for April, 1909, and April, 1910. These formulae, which unfortunately are not in general simple, were based upon the assumptions that the inverse square law and the cosine, or Lambert's law, could be applied to infinitesimal source areas without sensible error.

It was then shown both by experiment and by calculation that these two laws could be applied with a fair degree of accuracy to larger areas subject to certain conditions as to relative distance from the source.

In the course of the experimental work it was found that certain forms of glass showed a polar distribution of flux density that closely followed the inverse square law and cosine law when the source area was large enough to be practically useful and when the radius of the reading hemisphere was very little

[1] A paper presented at a meeting of the New York Section of the Illuminating Engineering Society, April 13, 1911.

greater than half the source dimensions. It then seemed to be of interest to obtain, if possible, by calculation expressions for the polar component of the total flux so that theoretically correct polar curves could be plotted for comparison with the experimental curves. It would thus be possible to determine how nearly the experimental surfaces exhibited theoretically perfect diffusion.

It is the purpose of this paper to present such a formula for

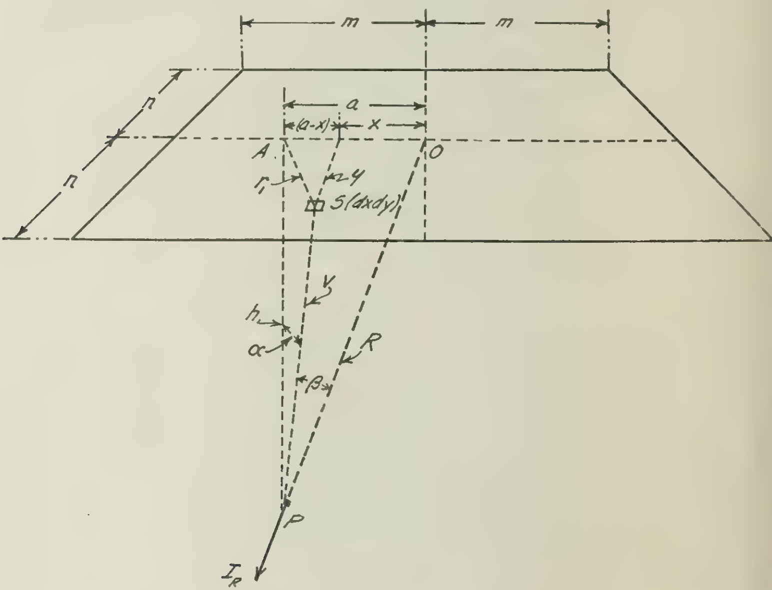


Fig. 1.—Photometric relations.

the polar component of flux due to finite surface sources, and, since in the course of this work the formula for polar component of the flux due to a line source will appear, to draw attention to it and to indicate its possible usefulness.

Let Fig. 1 represent a rectangular plane surface source of dimensions $2m$ and $2n$, and let it be required to find the component of the total flux along any radius drawn from the geometrical center of the source O, subject to the condition that the radius turns about O only in a plane perpendicular to the source and cutting the source along the m axis. Let the length

measured along the radius from O to the point P at which the illumination is required be R. Let the perpendicular distance, PA, from P to the plane of the source be h, and let $OA = a$. Let x and y be the orthogonal cartesian coördinates of the center of an elementary portion of the source, $dxdy$, with relation to O as origin. Draw the line PS from the center of this element to P and let its length be v. Let the angle between v and the normal to the surface be α. Then the angle SPA is also equal to α. Let the angle OPS be equal to β.

If i is the specific intensity of the source, as the component of the specific intensity due to $dxdy$ along v, there is obtained,

$$i_\alpha = i \cos \alpha \, dxdy.$$

The illumination at P along v, due to this element is then

$$i_v = \frac{i \cos \alpha}{v^2} dxdy,$$

and the component of the illumination at P along OP is,

$$i_R = \frac{i \cos \alpha \cos \beta}{v^2} dxdy. \qquad (1)$$

Now $$\cos \alpha = \frac{h}{v} \qquad (2)$$

and $$\cos \beta = \frac{v^2 + R^2 - r_1^{2*}}{2vR} = \frac{v^2 + R^2 - (x^2 + y^2)}{2vR}. \qquad (3)$$

But $$v^2 = d^2 + h^2$$

and $$d^2 = (a - x)^2 + y^2.$$

Whence $$v^2 = (a - x)^2 + y^2 + h^2$$
$$= R^2 - 2ax + x^2 + y^2$$

and $$v = \{ R^2 - 2ax + x^2 + y^2 \}^{1/2}.$$

Substituting these values in (2) and (3)

$$\cos \alpha = \frac{h}{(R^2 - 2ax + x^2 + y^2)^{1/2}}$$

and $$\cos \beta = \frac{R^2 - ax}{R(R^2 - 2ax + x^2 + y^2)^{1/2}}.$$

Whence,

$$i_R = \frac{ih}{R} \cdot \frac{R^2 - ax}{(R^2 - 2ax + x^2 + y^2)^2} dxdy. \qquad (4)$$

* NOTE:—r_1 should be drawn between S and O in Fig. 1; not between S and A.

The total illumination along R at P is, then

$$I_R = \frac{2ih}{R}\int_o^n\int_{-m}^{+m} \frac{R^2 - ax}{(R^2 - 2ax + x^2 + y^2)^2}\,dxdy \qquad (5)$$

$$= \frac{2ih}{R}\int_o^n \Big[\frac{(x-a)\,(R^2-ax)}{2(h^2+y^2)\,(R^2+y^2-2ax+x^2)}$$

$$+ \frac{R^2 - a^2}{2(h^2+y^2)^{3/2}}\tan^{-1}\frac{(x-a)}{(h^2+y^2)^{1/2}}\Big]_{-m}^{+m} dy$$

$$= \frac{ih}{R}\int_o^n \Big[\frac{(x-a)\,(R^2-ax)}{(h^2+y^2)\,(R^2-2ax+x^2+y^2)}$$

$$+ \frac{h^2}{(h^2+y^2)^{3/2}}\tan^{-1}\frac{(x-a)}{(h^2+y^2)^{1/2}}\Big]_{-m}^{+m} dy. \quad (6)$$

Putting the limits in the term under the integral sign there is obtained the following expression.

$$\frac{(m-a)\,(R^2-am)}{(h^2+y^2)(R^2-2am+m^2+y^2)} + \frac{h^2}{(h^2+y^2)^{3/2}}\tan^{-1}\frac{(m-a)}{(h^2+y^2)^{1/2}}$$

$$+\frac{(m+a)\,(R^2+am)}{(h^2+y^2)(R^2+2am+m^2+y^2)} + \frac{h^2}{(h^2+y^2)^{3/2}}\tan^{-1}\frac{(m+a)}{(h^2+y^2)^{1/2}} \quad (7)$$

each term of which must be integrated separately. Evaluating these integrals, there is obtained

$$I_R = \frac{ih}{R}\Big[\frac{y}{(h^2+y^2)^{1/2}}\tan^{-1}\frac{m-a}{(h^2+y^2)^{1/2}} + \frac{y}{(h^2+y^2)^{1/2}}\tan^{-1}\frac{(m+a)}{(h^2+y^2)^{1/2}}$$

$$+ \frac{m}{\{h^2+(m-a)^2\}^{1/2}}\tan^{-1}\frac{y}{\{h^2+(m-a)^2\}^{1/2}}$$

$$+ \frac{m}{\{h^2+(m+a)^2\}^{1/2}}\tan^{-1}\frac{y}{\{h^2+(m+a)^2\}^{1/2}}\Big]_o^n. \qquad (8)$$

and, finally,

$$I_R = \frac{ih}{R}\left[\frac{n}{(h^2+n^2)^{1/2}}\tan^{-1}\frac{(m-a)}{(h^2+n^2)^{1/2}} + \frac{n}{(h^2+n^2)^{1/2}}\tan^{-1}\frac{(m+a)}{(h^2+n^2)^{1/2}}\right.$$

$$+ \frac{m}{\{h^2+(m-a)^2\}^{1/2}}\tan^{-1}\frac{n}{\{h^2+(m-a)^2\}^{1/2}}$$

$$\left.+ \frac{m}{\{h^2+(m+a)^2\}^{1/2}}\tan^{-1}\frac{n}{\{h^2+(m+a)^2\}^{1/2}}\right]. \qquad (9)$$

If, in (9) there be put $a = 0$, then $R = h$, and the expression for I_R reduces to

$$I_h = 2i\left[\frac{n}{(h^2+n^2)^{1/2}}\tan^{-1}\frac{m}{(h^2+n^2)^{1/2}}\right.$$

$$\left.+ \frac{m}{(h^2+m^2)^{1/2}}\tan^{-1}\frac{n}{(h^2+m^2)^{1/2}}\right] \qquad (10)$$

which is the same as that given on p. 294 of the TRANSACTIONS for April 1910 for the illumination normal to a rectangular source at a distance h below its geometrical center.

Now, return to (6). If in this expression there be put $y = 0$, there will be obtained the value of the illumination along R at P due to a line source of length $2m$, when R lies in a plane through the source.

It is,

$$I_R = \frac{i}{2Rh}\left[\frac{m(R-a)^2}{\{h^2+(m-a)^2\}} + \frac{m(R+a)^2}{\{h^2+(m+a)^2\}}\right.$$

$$\left.+ h\left(\tan^{-1}\frac{m-a}{h} + \tan^{-1}\frac{m+a}{h}\right)\right]. \qquad (11)$$

If in (11) $a = 0$ then, since $R = h$,

$$I_h = i\left[\frac{m}{(h^2+m^2)} + \frac{1}{h}\tan^{-1}\frac{m}{h}\right] \qquad (12)$$

which is the expression for the illumination at distant h from the source on a line perpendicular to the source at its middle point, as may be readily proved by a simple calculation.

By means of (9) there may be calculated the values of illumination which will enable us to plot the polar curve in a plane perpendicular to either axis of a rectangular source for all values of R, m, and n.

By means of (11) there may similarly be plotted polar curves

for a line source, such as is approximated by a straight filament. The formula may also be used with reasonable accuracy for cylindrical sources, such as the mercury-vapor lamp when R is relatively great compared with the diameter of the cylinder and from such a curve the total flux emitted by the source may be computed. The expression for a retangular source (9) may be used when the diameter of such a cylindrical source is relatively large, or when the ratio of R to the diameter is not great. In such a case the source is considered as a narrow radiating strip, and the polar surface is obtained by revolving the polar curve about the source axis.

It is of interest to note the geometrical values of the several factors in (9). These are shown in Fig. 2.

In Fig. 3 are shown three polar curves for a square source where $m = n = 1$, $i = 10$. In curve 1, $R = 0.5$, in curve 2 $R = 1$ and in curve 3, $R = 2$. In curve 1, where R is less than m, as P approaches the plane of the source an imaginary screen at P perpendicular to R will be illuminated by less and less of the source, and hence, for large angles of obliquity the value of I_R will rapidly decrease. In curve 2, where $R = m$, as P approaches the plane of the source it is seen that the illumination steadily decreases until an obliquity of nearly 90° is reached when it falls abruptly to zero. In the case of a circular source this curve would be a semicircle of constant intensity $\pi i \div 2$ — one of Dr. McAllister's "Equilux Spheres." In curve 3 where R is $2m$, that is, where R is equal to the source dimension, the polar curve quite closely approximates a circle tangent to the source at its center. In the case of a circular source this approximation would be still closer, but as no exact expression for I_R is attainable for a circular source it is impossible to show that the polar curve of a flat circular source when R is greater than the radius of the source is or is not a true circle tangent to the source at its center. Of course an expression in the form of an infinite series may be found for the radial flux component due to a flat circular source by the method of harmonic analysis, but this expression is unwieldy and computation by means of it is generally exceedingly tedious. Whatever deviation there is, however, is probably negligible in practical application to actual sources.

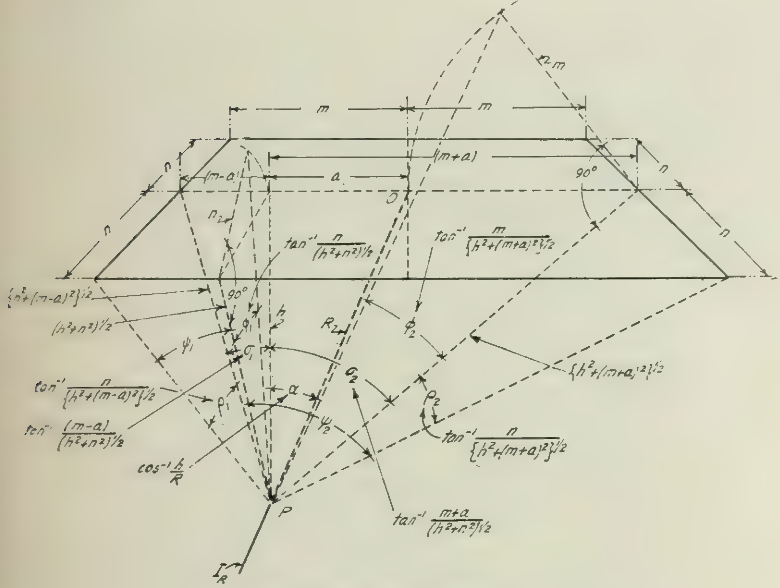


Fig. 2.—Photometric relations.

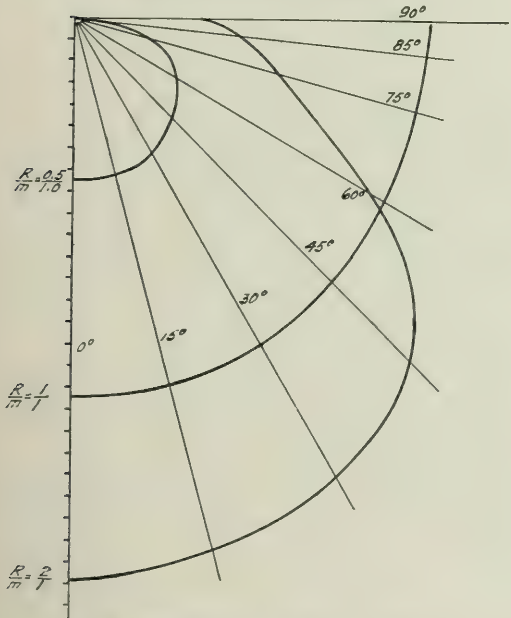


Fig. 3.—Square source. m = n = 1; h = 10.*

* The values of the ratio $\frac{R}{m}$ in Fig. 3, upper and lower curves, should be transposed.

It is interesting to compare with curve 3 in Fig. 3, the curves in Fig. 4, which are plotted from actual photometer readings

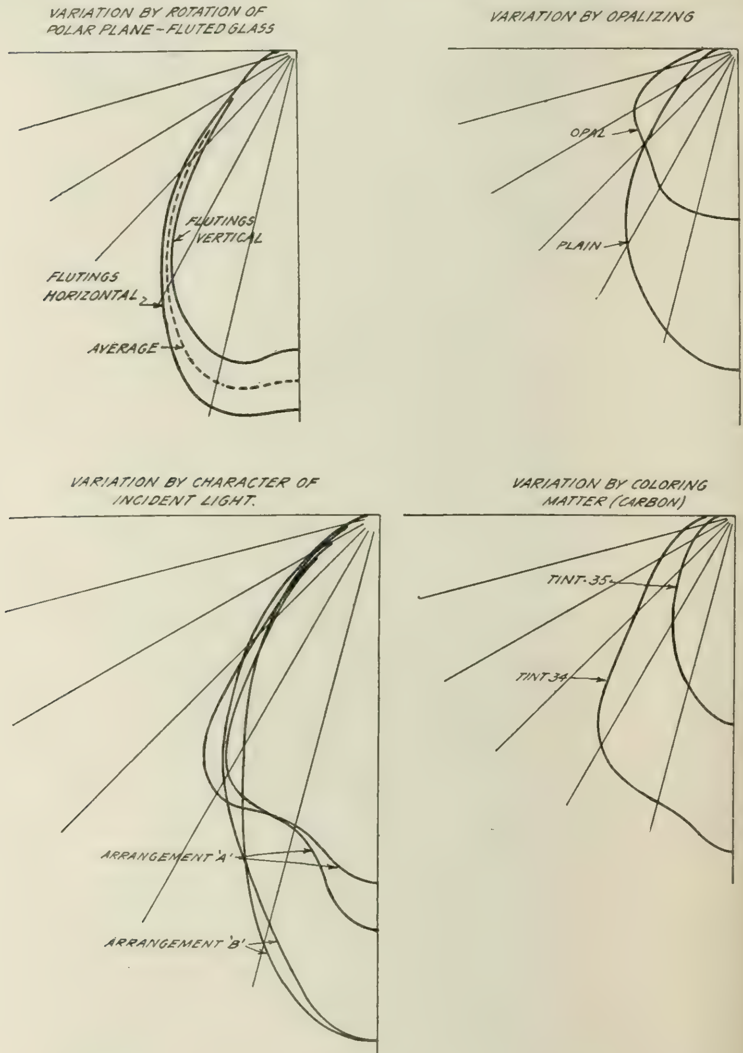


Fig. 4.—Variables due to character of source; in all cases, $m = n = 1.0$ ft., $R = 5.75$ ft.

of various sources of the same dimensions as the assumed source used in plotting the curves in Fig. 3. These curves also illustrate the general effect of certain variables entering into the

construction of such sources. In all cases in Fig. 4 R is greater than $2m$.

In Fig. 5 are shown two curves calculated by means of (11) for a theoretical line source where $m = 1$, $i = 10$. In curve 1 $R = 0.5$ and the polar curve is composed of two parts *a*, and *b*, the first asymptotic to the axis of the source, the second being the return bend of the curve along the axis when the obliquity of R is 90°. The form of this curve is due to the theoretical

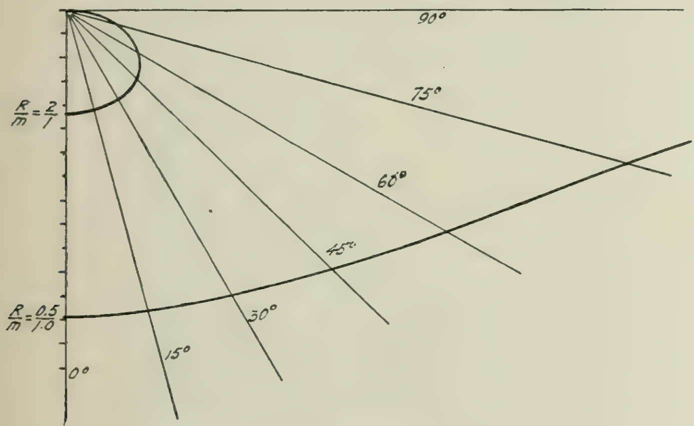


Fig. 5.—Line source, $m = 1$; $i = 10$.

consideration that in this case the intensity of the flux measured at P approaches infinity as P approaches the source axis. It is also to be noted that the calculation is based on the assumption that the source is of the nature of a geometrical line—the element of a plane source—and not the element of a cylindrical source. The ends of the source therefore emit no light. In curve 2, $R = 2$ and it is seen that the polar curve rapidly approaches a circle as the length of R becomes greater than m.

DISCUSSION.

Evan J. Edwards (Communicated):—Since so many light sources are circular or of other than rectangular shape in projection, it is unfortunate that a simple solution cannot be obtained for a more general case than that for which the equation as presented by Mr. Jones will apply. This problem serves as a notable example of the difficulties which may sometimes be en-

countered in computing a quantity which depends for its value on only very simple laws. The equation as given by Mr. Jones is limited to the very particular case of a rectangular surface, to a line of direction always including the geometrical center of the source, and, moreover, to points lying in but two planes perpendicular to the source.

Although light giving sources are rarely rectangular in shape and uniform brightness, much information which is of practical value is given by such an analysis. For example, it may be seen that the error in computation due to assuming a point source becomes of the order of magnitude of 1 per cent., at a distance away of five times the source dimension.

An idea of the difference between the distribution of a circular source and a square source is obtained from the fact that the figure for the total flux as obtained from the distribution curve taken at a distance away which includes all of the source, is about 85 units, as compared with 126 units which are actually radiated. The discrepancy is, of course, due to the polar value as given on the curve, being the minimum rather than the average value of illumination about a zone.

Some very interesting deductions are obtained by substituting various limits in the equation as given by Mr. Jones. Making the limits of the source dimension infinite, there is obtained, using the notation of Mr. Jones' paper:

$$\mathrm{I} = \pi i.$$

that is, the illumination at any point along a line perpendicular to an infinite plane is a constant and equal to π times the brightness of the source. This result is approximated in a large room illuminated indirectly by the ceiling. It is even more closely approximated in the case of outdoor horizontal illumination from an overcast sky.

Placing for one source dimension the limit zero and for the other infinity there is obtained:

$$\mathrm{I} = \frac{\pi i}{2h}.$$

which shows that for a very long line source the illumination is

inversely as the distance away. There are, therefore, three extreme cases as regards source dimension, which obey very simple laws; the point source for which the illumination is inversely as the distance to the second power; the long line source for which the illumination is inversely as the distance to the power, and the very large source area for which the illumination is proportional to the distance to the zero power, that is, independent of the distance. All limiting cases admit of very easy solution while those which lie between are in the most part very difficult.

In the comparison of the experimental curves with those obtained by computation, it may be of interest to know more about conditions under which the photometer curves were obtained.

The geometrical significance of the various terms of an equation is well illustrated by the diagram of Fig. 2, of Mr. Jones' paper, and is very interesting.

Mr. Bassett Jones, Jr. (Communicated in reply):—Equations for "general cases" are usually quite as "general" and impractical as the general cases themselves. Unfortunately and contrary to Mr. Edward's experience I have been compelled to work rather generally with rectangular surfaces. I have therefore been obliged to find a formula for the flux density, in the form given, for comparison with polar curves taken only in the two planes mentioned as being the only results of immediate practical importance so far as I am concerned.

The experimental sources used are practically uniform in brightness—at least so uniform that the eye can detect no variations. This uniformity was the result of a large amount of experimental work undertaken with just this result in view.

An account of the methods of constructing such sources, together with an account of the method of photometering such surfaces, must be left for some future opportunity. The results practically applied were described in my recent paper "The Lighting of the Allegheny County Soldiers' Memorial."[1]

I have been informed that it is easier to find a formula for finite circular sources than for finite rectangular sources. This I can believe, in view of the difficulties and seemingly inexorable

[1] TRANSACTIONS Illuminating Engineering Society, Jan., 1911.

snarls from which I have extricated myself with the result shown in equation (9). I have tried circular sources and got into all kinds of trouble which is, in mathematics, a fair indication that one is on the wrong track. However, the results for circular sources in my previous papers have been given in the hope that somebody would undertake to work out something better.

SIGN LIGHTING.[1]

BY O. P. ANDERSON.

The growth of the illuminated sign business during the last few years has been remarkable. A dozen years ago the illuminated sign in most cities was a curiosity. New York had probably a score of signs of this kind; Chicago had even less. To-day the number of these signs in the two cities runs into the thousands; and many of them contain thousands of electric lamps. Practically all the spectacular signs which now illuminate Broadway, New York, have been erected during the last five years, and the same is true in other cities. This growth has been a substantial one, and the present indications are that the sign business will continue to grow at an ever increasing rate. Heretofore, central stations have not given the attention to this phase of the lighting business that it required; but now that its remarkable possibilities have been demonstrated by the rapid growth of the past five years they have awakened to a full realization of its importance.

The electric sign has created a new type of advertising essentially different from all previous forms. It has filled and is filling an economic need. As the size of our cities and the number of merchants have increased, it has become necessary for a merchant to designate the location of his store in some way. In a few cases of course the size and architecture of a store are sufficient to advertise its location. For instance, if a firm were to locate in a building like the Flat Iron Building, New York, the majority of the people would have no trouble in finding it. Many of the stores, however, are located in more or less inconspicuous places, and are liable to be overlooked. To avoid this the merchant employs some method of outdoor advertising which will tell the people just where he is located.

The modern merchant knows the value of signs. The only doubt in his mind is the relative advertising efficiencies of the different types of signs. He may elect to use street car signs, glass signs, bill board signs, etc., or electric signs; these all

[1] A paper presented at a meeting of the New York section of the Illuminating Engineering Society, April 13, 1911.

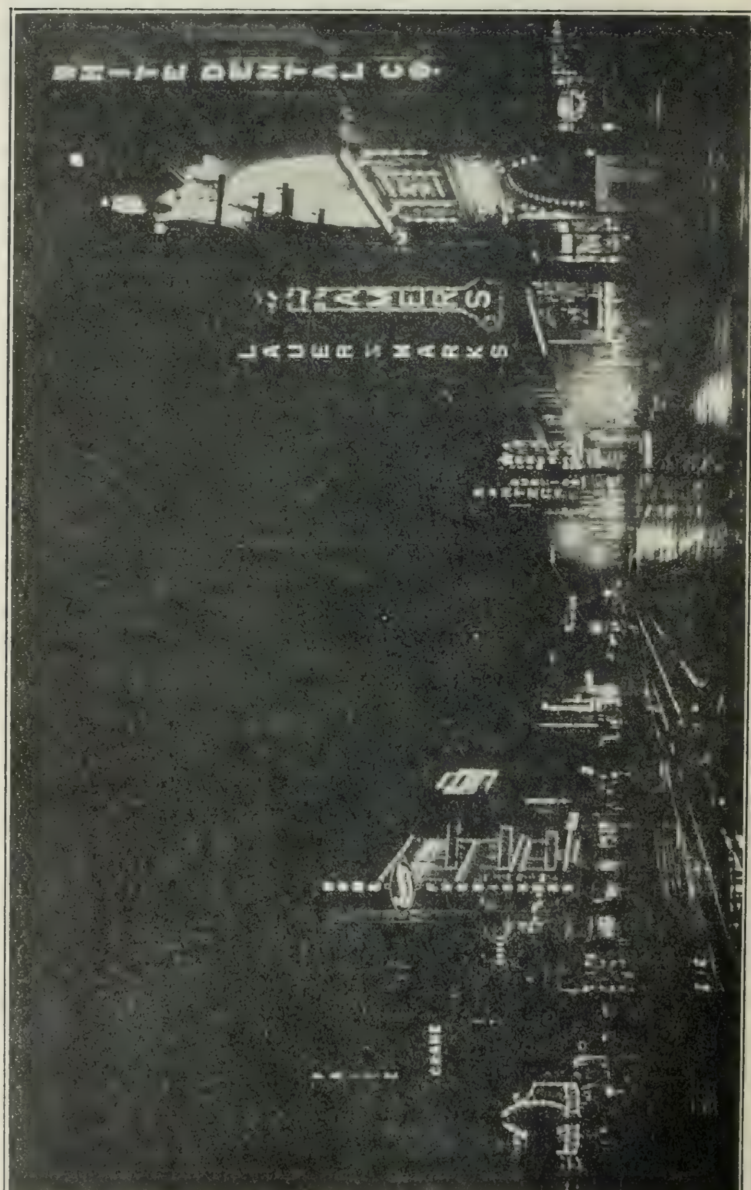


Fig. 1.—Lackawanna Avenue, Scranton, Pa.

have their advantages for general outdoor advertising. So extensive, however, is the present use of electric signs that a brief consideration of the reasons why they are effective advertising agencies may be interesting.

In the first place the distinctive difference between illuminated advertising and all other forms of advertising is the element of light. As an advertising medium light has always been successful, because it attracts and holds attention. One is instinctively attracted by almost any form of light. The wonderful northern lights, for instance, attract thousands of people every winter night. Imagine this light confined and concentrated into a single sign flashing across our northern sky. What an attractive power it would have. The reflection of a distant fire never fails to attract attention. Amusement places such as Coney Island are concrete examples of the attractive power of light. The boardwalks of our famous summer resorts are splendidly illuminated to attract attention. In fact, people are attracted toward light in a manner not unlike that of the moth. This has been observed so many times that one might attempt to formulate a law.

Secondly, the electric sign has a greater "circulation" than any other type of sign, other things being equal. A carefully designed sign placed before the people will be read by at least the majority of them. Some of them may read it unconsciously. Nevertheless the advertiser produces on the mind the impression that he has something to sell. Furthermore, it is evident that the greater the number of people who read the sign the greater will be its advertising value. A large spectacular sign placed where no one could see it would of course be of no value; but the same sign placed on or near a thoroughfare like Broadway would have a tremendous advertising value. Broadway, between 14th and 42d Streets has a circulation estimated at 700,000 people daily. The Brooklyn Bridge has a circulation of approximately 500,000 people daily. Obviously a sign along a throughfare like one of these will be read in a short time by a vast multitude.

A short time ago the "Dutch Cleanser" sign was erected in Omaha and representatives of the central station and the

advertisers made a test to determine the value of the sign. They observed that practically every person passing a point a block away from the sign looked at it. That the sign was effective advertising was proved conclusively.

A third reason is that the electric signs help to illuminate streets. It was proved in Denver a while ago that the number of people passing through any street at night was directly proportional to the extent of the general illumination. This means that other things being equal the street having the most signs will have the most illumination and will tend at least to attract a greater proportion of the people. It has been observed also in several cities that the business center may be shifted to

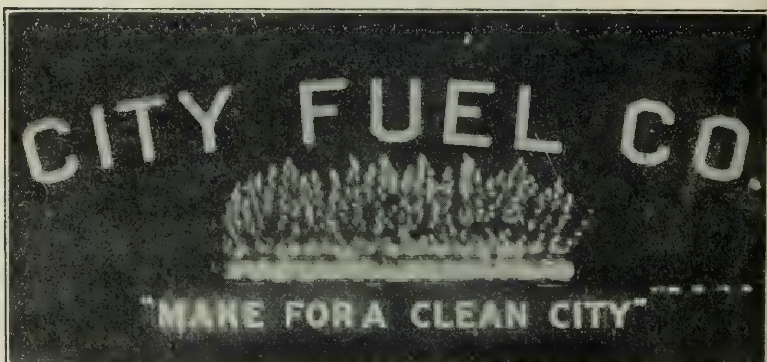


Fig. 2.—Double-faced block-letter sign.

another section of the city where there is more illumination. In Newark, New Jersey, for instance, a few years ago the street illumination was very unsatisfactory. The merchants along Broad Street decided to install flaming arc lamps on that street. This was done with the result that a "White Way" was created which attracted the people to that street. The merchants on Market Street discovered that their trade was being diverted to Broad Street, and, in order to protect their business, they too installed flaming arc lamps. To their satisfaction they observed that the business which had been diverted from their street began almost immediately to return to it.

CLASSES OF SIGNS.

Signs may be grouped into two broad classes: (1) those which burn steadily; (2) those which burn intermittently. Each of these two classes may be subdivided into horizontal, vertical, single- or double-faced signs. Or they may be classed according to location, that is, roof signs, signs placed flat against a building, or signs swinging at angles to the building.

In the first class there are several types of signs which may be

Fig. 3.—Roof sign showing channel type letters.

mentioned. Of these the *reflector* sign is the simplest type. It consists merely of a painted panel with a hood located at the top which acts as a reflector directing the light upon the reading matter. The *panel* sign is the oldest and most common type. It consists of a painted panel surrounded by a border of lamps. The *transparent* sign is very simple and is used in many installations. In a majority of cases, however, it is not to be

recommended, although a few of the newer signs of this type are very attractive and efficient. The roof sign is a comparatively new sign and one that is rapidly coming into favor. It has the advantage of being more conspicuous than any of the other signs which burn steadily.

In the second class there are two types of signs which are to-day used extensively—*talking* signs and *flashing* signs. The talking sign is composed of a number of monograms and is capable of automatically flashing forty or more words or sen-

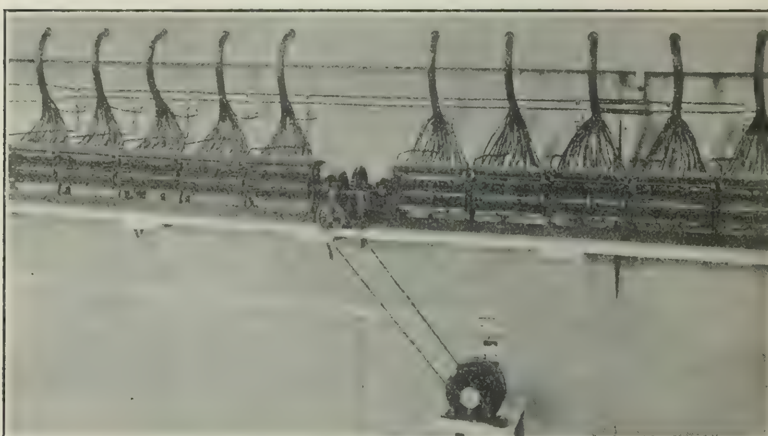


Fig. 4.—Talking sign flasher.

tences. Each monogram contains a number of metal troughs with a lamp in each. Each monogram is also connected to a commutator, by means of which various letters or figures are formed. The number of monograms necessary is determined by the longest sentence displayed. For a double-faced sign of course, twice the number of monograms and commutators are necessary. Where a talking sign is used exclusively by one firm it is an excellent advertising medium. But when a sign of this kind is used by several firms in the same locality its value to each firm is very much decreased.

Signs of the *flashing* type are effective because of their apparent motion. The motion element is what attracts and holds

attention. Any object may remain motionless within one's field of vision and probably not be noticed; but let that object move and it will be perceived instantly. An eagle perched on a treetop may remain unnoticed; but if it soars from its perch it will attract attention at once. The same is true of flashing signs. People gaze in wonder at the modern spectacular sign because it has motion and gives the impression of life. Parenthetically, it may be said that *flashing* signs are of greater advertising value than those signs which are operated steadily. It is not enough, however, for a sign to produce only the impression of motion. It

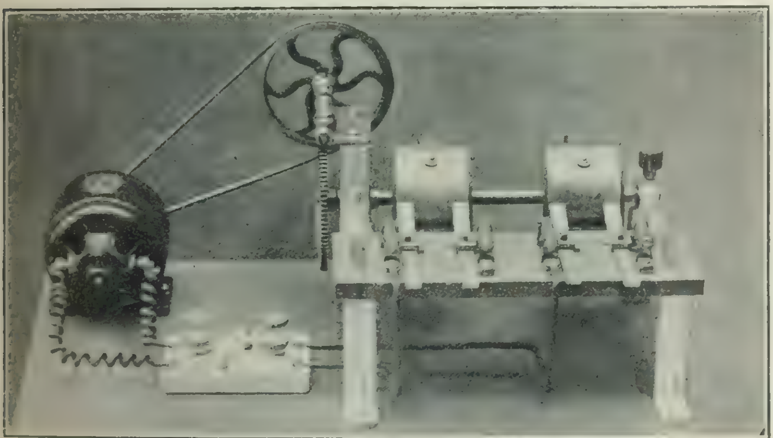


Fig. 5.—Sign flasher.

must have some features which make it distinctly different from other signs in the same vicinity. If all the signs except one in any locality were flashing signs undoubtedly the sign which burned steadily would have the greatest attracting power. As an illustration of this the crowd passing through any street may be noticed. As long as a man moves with the crowd he is not noticed; but if he stands still he will attract attention. For that reason many installations may be observed where there are different kinds of flashing signs. Two types in particular may be noticed, one an ordinary flasher where the entire sign flashes on and off at once, the other where the reading matter is displayed continuously while the rest of the sign flashes on and off.

In some flashing signs the motion itself, which is produced by the lights, tells the story to be conveyed by the advertisement. A bowling game in which a ball flashes along an alley, for instance, advertises the bowling alley very effectively. The flashing effect

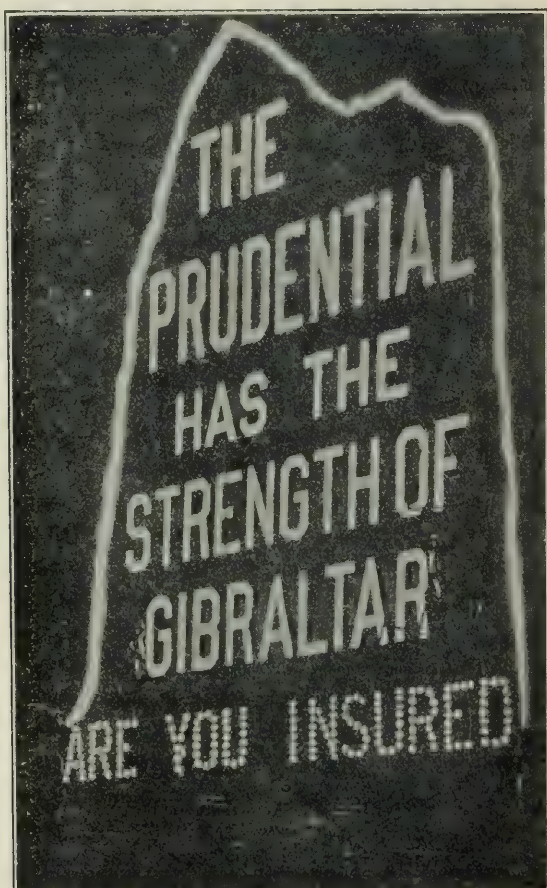


Fig. 6.—Combination flashing and talking sign.

of a great many signs is employed merely to attract attention to the reading matter of the sign. The "rat-chasing" and the "sky-rocket" effects are examples of this kind of sign. Still other signs of this type spell out letter by letter. When a person notices a sign

of this character he will in all probability watch the sign until the word or sentence is completed. He is literally compelled to read what the advertiser has to say.

There are many unique and original signs in operation. In any large city one may see fiery chariot races, automobiles whizzing through the air, or almost be tempted to raise an umbrella to ward off the gently falling rain seen in a nearby sign. One may watch a game of billiards, or a couple of snakes chase each other around a liquor sign, or a church steeple crowned by a flaming cross. Movements of every description are produced in almost true life. There is no gainsaying the fact that these signs attract people and compel their observation. These signs not only tell their stories in a startling and convincing manner, but they constitute effective advertising.

CONSTRUCTION OF SIGNS.

To produce the best results signs should be carefully constructed, as good material and workmanship are very essential. The sign should be erected in such a way as to be safe and to appear safe. Nothing hinders the sign business so much as a sign swinging and creaking in the wind. In many instances the electric sign has been criticised as an "eye-sore." In order to offset this criticism it is necessary that a great deal of care be taken in their design and whenever possible they should harmonize with the architecture of the building on which they are erected. It is obvious that a sign placed on a bank should differ in design from one placed on a cigar store. Furthermore, it is essential that a sign be properly maintained after it has been installed. It should be washed at regular intervals and the burned-out lamps be promptly renewed. The increase in current by virtue of having all the lamps burning will practically pay for the expense of replacing the lamps. Hence this part of the maintenance is often cared for by the central station. A dilapidated or dirty sign causes unfavorable criticism from the public and defeats the very purpose of the sign.

Letters.—The letters used on signs may be grouped into four classes: (1) flush, (2) raised or block, (3) sunken or groove, (4) channel or wall. When a sign made of flush or block letters is placed flat against a building it can be read only within a

comparatively small angle, due to the fact that the projecting lamps often overlap in the line of vision and produce a blurred effect. For a sign of this kind the sunken or channel letters are preferable. They can be read through a wider angle because the lamps are not in view. The letters can be seen not by the location of the lamps but by the reflected light from the outline of the letters. This makes the letters stand out sharp and clear.

A very important detail in the construction of a sign that is often disregarded or improperly considered is the spacing between the letters. In many a sign the greatest effect is often lost because an advertiser wants to say too much in a very small space. At the same time he wants to keep down expense. The result is that the letters must be crowded and made small. Such a sign, of course, can be read within only a comparatively short distance. Obviously, it is better to use a few words with large letters.

Wiring.—The introduction of the low-voltage tungsten sign

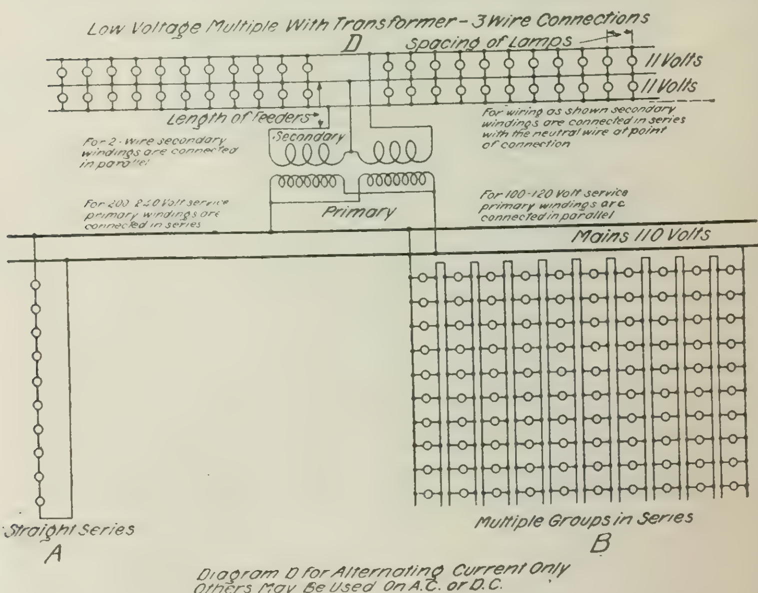


Fig. 7.

lamp has necessitated slight changes in the method of wiring, as the carbon sign lamps are practically all wired in multiple. It is not

possible at present to manufacture a 5-watt, 110-volt tungsten lamp. The specific resistance of tungsten is very low and to obtain small wattages on 100- to 125-volt circuits the filament must be made very long and fine so as to afford the requisite resistance. Tungsten lamps of 100 to 125 volts are not made at present for less than 25 watts. To obtain the small candle-powers required for signs it is necessary to use heavy filaments of low voltage. In this way a rugged lamp is obtained one which, on account of its short filament, can be made with a bulb of the same size as the carbon sign lamp. The heavy filament also makes possible a lamp of very much longer life than one with a fine filament of the same efficiency. Such a low-wattage lamp must be a low-voltage lamp, and, of course, it is necessary to reduce the line voltage. In using these lamps on standard lighting circuits, when alternating current is used, this can be done by means of transformers which will step down the voltage from 110 volts to 11 volts. The lamps can then be wired in multiple to produce satisfactory results. When only direct current is available, however, some other method of wiring must be employed.

The two methods of wiring that are used for direct current are series and series multiple. In series wiring the lamps are connected in series directly across the mains and the number of lamps in series is determined by their voltage and the voltage of the mains. The chief objection to this method is that when one of the lamps burns out the entire series goes out. When this happens it is often a rather tedious job trying to discover the lamp that has burned out. It has, however, the advantage of necessitating an immediate replacement of the burned-out lamp where results from the sign are to be obtained. The lamps should be selected for series burning.

Series multiple is the more ideal method of wiring for direct current. It is not possible though to use this method unless there are at least 80 lamps in the sign, and it is not advisable to use less than 100 lamps. The lamps are wired in multiple and then the multiple groups are wired in series. A sign containing 80 lamps and having ten groups in series would have 8 lamps in each multiple bank. If one lamp burned out the remaining seven lamps would operate at a slightly higher efficiency and the life

would be somewhat shortened. But when a large number of lamps are used in a sign the failure of any lamp will not affect the others to a great extent. A series multiple sign, therefore, should contain from 100 to 150 lamps.

The central station which supplies direct current need not fear the use of tungsten sign lamps in series or series multiple. In one city having 250 volts direct current signs with twenty-

COURTESY N. Y. EDISON CO.

Fig. 8.—Roof signs, Broadway, New York.

six of these low-voltage tungsten lamps are wired in series and very little trouble is experienced. In fact both these methods of wiring (Fig. 7) are giving satisfaction.

A sign containing tungsten lamps on direct current cannot flash less than ten lamps at one time, for it is necessary that at least that many lamps be connected in series. Where spectacular effects are to be produced it may be necessary to use carbon lamps to bring out a few of the effects. Nevertheless, it is always possible to use tungsten lamps for parts which burn steadily. In a majority of the signs this will cause a great saving. Where

alternating current is available, and the voltage is stepped down to the voltage of the lamps, single lamps can be flashed in the same way as carbon lamps. When the number of circuits is comparatively small and the size of the sign will permit, the flashers may be located on the high tension side. This is desirable because of the smaller currents carried.

Where direct current is used for sign lighting and it is desired to change from carbon to tungsten lamps, many electricians suppose that the sign has to be completely rewired. This is not only unnecessary, but is a needless waste of time

Fig. 9.—Method of changing regular multiple sign wiring to series for tungsten sign lamps.

Fig. 10.—Method of changing regular multiple sign wiring to series multiple for tungsten sign lamps.

and money in most cases. Figs. 9 and 10 show how quickly and simply the wiring can be changed. To change from multiple to series multiple (Fig. 10) the wire is cut on alternate sides of equal groups of lamps. In Fig. 10 eighty lamps are used and the wire is cut on the alternate sides of each group of eight lamps. A wire for the return circuit is all that need be added.

In wiring signs containing tungsten lamps care must be taken to provide the proper sized conductors, as the heavy currents may cause considerable line drop. A voltage drop of 0.5 volt is about the maximum that should be allowed, as a larger drop will produce a visible decrease in candle-power.

In Table No. 1 are given the maximum number of 0.5-ampere lamps that can be supplied by feeders having the length and size given in the table with a voltage of not exceeding 0.2 volt.

TABLE NO. 1.

Combined length of pair of feeders	Size of feeder (B. & S.) 10	8	6	4	2	
3	64*	92*	130*	184*	262*	
4	50	77	125	184*	262*	
5	40	62	100	158	254	
6	33	53	84	135	210	Number
8	25	40	63	101	160	of
10	20	31	50	79	127	lamps
15	13	21	33	53	85	
20	10	15	25	39	63	
30	7	10	17	26	42	

In Table No. 2 are given the maximum number of 0.5 ampere lamps that can be run in multiple with a drop not exceeding 0.5 volt from the middle of the bank to the outermost part.

TABLE NO. 2.

Spacing of lamps in inches	Size of wire (B. & S.) 14	12	10	8	
3	64*	92*	125*	159	
6	55	70	88	112	
8	47	60	75	97	Number
10	42	54	68	86	of
12	38	49	62	79	lamps
16	33	42	54	68	
20	29	38	48	61	

Lamps.—Of the two classes of sign lamps in use to-day the carbon lamp is the one most commonly used and is the one with which central station men are most familiar. These lamps are made in voltages from 45 to 130. The sizes most frequently used are the 2-c-p., 10-watt; and 4-c-p., 20-watt. They have a carbon filament and are rated at approximately 5 w.p.c. with a total life of 2,000 hours. They are rugged lamps and have given very satisfactory service. The candle-power of these lamps will decrease until the lamps burn out, at which time it may be about 60 or 50 per cent. of the initial candle-power.

The other class of sign lamps in use to-day is the tungsten lamp. This lamp although comparatively new has become quite popular. Although it can be made in a large range of voltages the standard voltage is from 10 to 13. This low voltage insures a short, thick filament which is very rugged. The lamp is sup-

* This number cannot be increased without exceeding the safe current carrying capacity of weather proof wire as allowed by the National Electric code.

plied with either a M- or V-shaped filament. The V-shaped filament gives the more satisfactory service, has sufficient end on candle-power, and the light from the side of the filament is useful in illuminating the sides of the letters. The life of this lamp is also 2,000 hours at an efficiency of 1.31 w.p.c.

The tungsten lamp possesses several advantages over the carbon lamp, the most important advantage being, of course, the increased efficiency. This increased efficiency is partly due to the higher temperature at which the tungsten filament operates. Hence the intrinsic brilliancy of the tungsten lamp is much greater than that of the carbon lamp; and high intrinsic brilliancy is what is desired. Furthermore, the decrease in candle-power of the tungsten lamp during life is very small, the drop being only from 10 to 15 per cent. during the entire life of 2,000 hours. A practically uniform quality of light is therefore insured.

OSCILLOGRAMS AND PHOTOMETRIC CURVES.

Oscillograms.[1]—The oscillograms shown in Fig. 11 illustrate the electrical characteristics of the various classes of incandescent lamps. The carbon-filament has a negative temperature co-efficient, the resistance being greatest when the filament is cold: hence, as the current is turned on and the filament gradually heated the resistance is decreased. From the curve it is seen that it takes an appreciable time for the current to reach it normal value. The metallized filament has a negative temperature co-efficient when the current is first turned on, but in about four one-hundredths of a second its electrical characteristics change and the co-efficient becomes positive. The tantalum and tungsten filaments have positive temperature co-efficients throughout.

As the resistance of the metal filaments is comparatively low when they are cold, the instant the current is turned on it reaches several times its normal value. This is known as "over-shooting" and causes the lamp to light up brilliantly at once. Sign lamps operated at high speed by flashers must light up instantly. From the oscillograms it will be observed that the

[1] Test of tungsten lamps by T. H. Amrine and A. Guell, Univ. of Illinois, Bulletin No. 23. Comparative tests of carbon, gem and tantalum lamps by T. H. Amrine, Univ. of Illinois Bulletin No. 16.

tungsten lamp has a great advantage in this respect, as it will reach its normal brilliancy in about one-third of the time of the carbon lamp. The effect of "over-shooting" upon the life of the lamps is not as serious as it would appear to be, as the ex-

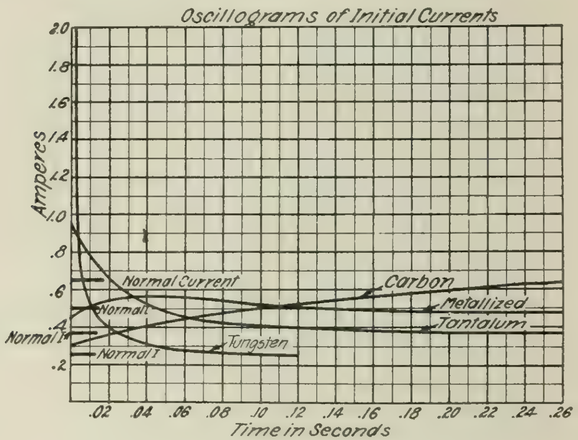


Fig. 11.

perience with tungsten lamps in actual operation by flashers seems to indicate that the life will not be decreased by any appreciable amount. If the lamps are flashed so frequently that the filaments do not cool, the effect of "over-shooting" is decreased and hence the life of the lamps is practically not decreased.

Photometric Curves.—The photometric curves given in Figs.

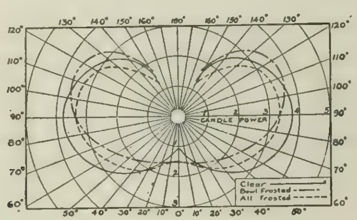


Fig. 12.—Polar distribution curves of tungsten sign lamps.

12 and 13 show the effect of frosting on the distribution curves. Although the tip candle-power is increased somewhat, the total

light flux is decreased. When a sign is hung close to the sidewalk, it is necessary that the lamps be frosted in order to diminish the glare. When the signs are placed at a considerable distance above the sidewalk, however, the frosting of lamps is not to be recommended. It acts as a trap for dirt and greatly decreases the candle-power. The increased tip candle-power is

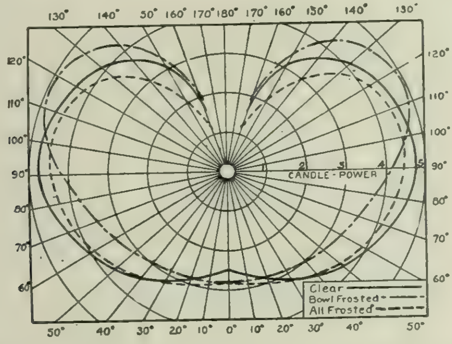


Fig. 13.—Polar distribution curves of carbon sign lamps.

not a great advantage, as signs are seen not so much by the direct light from the lamps as by the light reflected from the back and sides of the letters.

In producing various artistic effects colored lamps are often employed. It is possible to obtain sign lamps in either natural or artificially colored bulbs. Colored caps are sometimes placed over the clear lamps. These caps not only protect the tungsten lamps but give the desired color effect. Colored bulbs will of course decrease the total light flux to a considerable extent, but when colored effects are desired the efficiency is no longer the determining factor.

OUTLINE AND BILL-BOARD LIGHTING.

Outline Lighting.—The outlining of buildings by means of incandescent lamps is clearly a form of illuminated advertising and hence deserves consideration at this time. Prominent outline lighting is a branch of exterior illumination which in the past has received very little attention. Only during large celebrations and expositions have extensive exterior displays been made. And

as these displays were usually temporary and hurriedly arranged, the effect produced could not be called artistic. Buildings were outlined by stringing a few rows of low candle-power carbon lamps along some of the principal lines of the building. This method has been severely criticised by architects for the reason that only in a few instances were the important architectural features brought out. In most cases a row of lamps was strung down each corner and along the cornice; the rest of the building was left in gloom. For permanent outline lighting such effects are, of course, to be condemned. What is wanted is not a geometric outline, but the illumination of the principal architectural features of the building. In order to improve upon these unsatisfactory methods it is necessary to place the lamps so that they will not only bring out the dominant architectural features but will illuminate the entire building. The new office building of the Denver Gas and Electric Co., is a splendid example of good modern outline lighting. The lighting of this building is the finest example of facade lighting ever attempted. Thousands of brilliant tungsten lamps are used to bring out every detail of the building and the result is wonderful.

Bill-Board Lighting.—Bill-board lighting is a very important phase of the sign lighting business. To-day our cities contain miles and miles of bill-boards which are not illuminated in any way; the advertisements are displayed only in the day time. These advertisements represent an investment of a considerable amount of money, and therefore the greatest possible amount of advertising should be secured. By illuminating these bill-boards it is possible for the advertiser to get twenty-four hours of advertising a day instead of twelve. Besides giving more hours of advertising the light makes the sign so dominant that its advertising value is greater by night than by day. From an artistic point of view the illuminated bill-board is not a success, and its advertising value is not as great as that of the all-lamp sign Nevertheless, the use of illuminative bill-boards is growing rapidly, and it is only a question of time until they will all be lighted in this way. Although such a type of sign is not to be recommended in the case of a new installation, yet the illumination of old bill-boards is to be recommended from the central station point of

view. Undoubtedly in the near future not only will the bill-boards in the cities be illuminated, but the bill-boards in the

Fig. 14.—Denver Gas & Electric Company building, Denver, Col.

country along the railroad tracks will also be illuminated. This can be done by means of batteries and time switches.

CONCLUSION.

The sign business at present is growing more rapidly than any other phase of the electrical business. And notwithstanding the remarkable growth of the last decade, a great part of this field of lighting still remains undeveloped. Admittedly, also, many blunders have been made in this industry, as in other industries; but by correcting these mistakes and erecting suitable signs in all new installations electrical advertising will advance even more rapidly than it has in the past.

DISCUSSION.

G. G. Freygang:—What in your opinion are the advantages of the V-shaped filaments over the M-shaped filaments?

Mr. Anderson:—A sign letter is seen by the light coming directly from the lamp and also by the light which is reflected from the letter. When a sunken or channel type letter is used, it is evident that the filament should have such shape that the sides as well as the back of the letter are illuminated. In such case a large end-on candle-power is not of any particular advantage; in fact, it is a disadvantage, as the effect is blurred. The V-shaped filament has sufficient end-on candle-power and enough side-on candle-power to illuminate the letter uniformly, and hence, is the more desirable for this type of letter. In the case of a flush letter it would appear that the greater end-on candle-power of the M-shaped filament is an advantage. My experience however seems to indicate that a flush letter equipped with lamps having a V-shaped filament can be seen as clearly and at as great a distance as when equipped with lamps having a M-shaped filament.

W. Warren Tower:—I should like to ask why it is the light of the natural colored lamp is less than that of the clear lamp?

Mr. Anderson:—The life of a lamp depends to a large degree upon the temperature at which the filament operates. If an incandescent lamp were operated in an oven of a high temperature its life would be shorter than if operated under normal conditions. The coloring absorbs a considerable amount of the radiant energy,

and hence raises the operating temperature of the lamp. The relation between the life and the color of a lamp depends upon the absorption coefficient of the coloring used. The absorption coefficient of a blue color is greater than that of a red or a yellow color, and for that reason blue colored lamps have a relatively shorter life than a yellow colored lamp.

TESTS ON LIGHTING OF A SMALL ROOM.[1]

BY JAS. R. CRAVATH.

It has occurred to the writer that although many valuable tests of illumination have been presented to this society, there has been a remarkable scarcity of tests in small rooms approximately 15 by 15 feet and from 8½ to 10 feet high. As there are doubtless more rooms of about this type than any other kind in existence, the illuminating results obtained in such rooms should rightfully receive much study.

The object of the present paper is first to show what results are actually obtained in rooms of the type mentioned with several common artificial lighting arrangements, and second to compare the measured efficiency of several methods in common use at the present time. The question of shadows is also studied.

THE ROOM USED.

The room in which these tests were carried out is the living room in the writer's home, the dimensions of which are 12 feet by 16 feet 6 inches. The ceiling height is 8 feet 6 inches. The ceiling color is very light cream. The walls are light green rough paper. A plan of this room is given in Fig. 1. During the test the large door spaces were provided with red portieres and green window shades were drawn down over the windows. The rug was dark red and the woodwork and floor natural oak finish. The fireplace in one corner of the room is of light colored brick.

For purposes of this test only one-fourth of the room was taken, the test stations being indicated on the plan Fig. 1. It was assumed that the results in this quarter of the room represented the true average results for the whole room. While this may not be literally true, it is believed to be near enough true for all practical purposes. The furniture in the room was arranged as in ordinary use except in the quarter in which the tests were being made. All the tests were made in the same quarter of the room. This quarter was divided into equal

[1] A paper presented at a meeting of the Chicago Section of the Illuminating Engineering Society, March 16, 1911.

rectangles, each rectangle being 2 feet ¾ inch by 3 feet and a test station was located at the center of each rectangle. The numbers on the test stations in Fig. 1 corresponds to the numbers given on the schedule of the various tests.

The room has an outlet at the center of the ceiling. In all

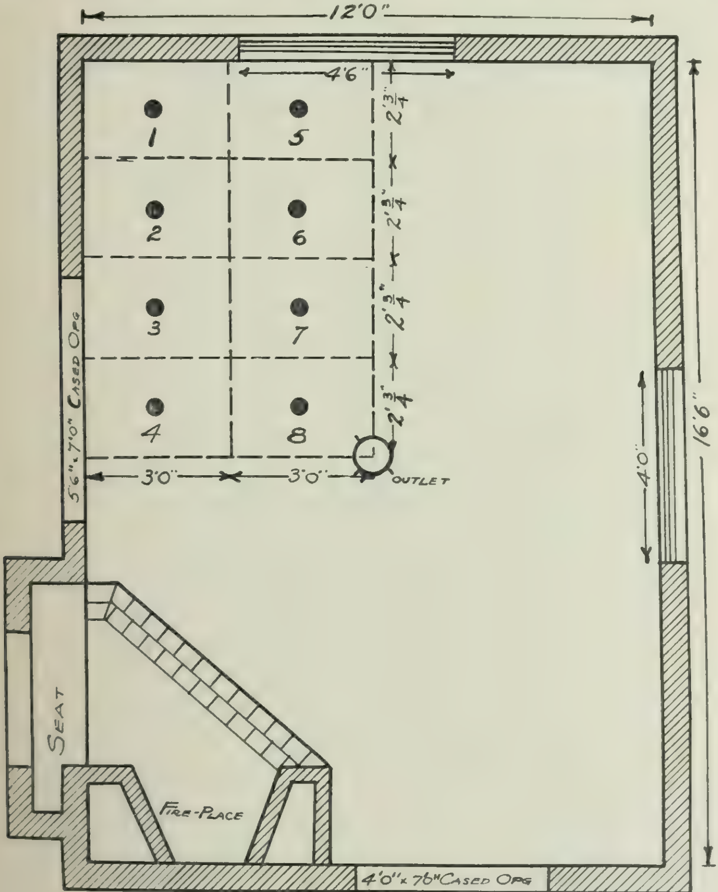


Fig. 1

the tests, except those for indirect and semi-indirect lighting, the lamp was placed as close to the ceiling as an ordinary brass shell ceiling socket would permit, namely, about 8 inches for the 100-watt tungsten lamp used.

It will be seen that the room is of a size which is very common. Many rooms of this size, however, have ceilings from 6 inches to 18 inches higher.

METHODS OF TEST.

All the tests were made with the same tungsten lamp of 100-watt nominal rating. In order to eliminate personal and instrument errors as far as possible, the same set of instruments were used both in testing the candle-power of the 100-watt tungsten lamp used during the test and in making the illumination tests, and the photometric readings were all taken by the same person. Before the test the tungsten lamp used was placed on a screened photometer bench at a measured distance from the test plate of a Sharp-Millar photometer. For this candle-power test the photometer was arranged to read foot-candles just as for the illumination tests made later, in order to eliminate any possible error by a discrepancy between the foot-candle and candle-power measurement arrangement provided on this photometer. By this method 40 readings were taken of the horizontal candle-power of the lamp used and the mean of these was taken as the mean horizontal candle-power. Voltage readings were taken simultaneously with the photometer readings.

In testing the illumination, the same Sharp-Millar photometer and Weston mil-am-meter were used, and the photometer was set on a table with the test plate 3 feet 6 inches from the floor. The same Wagner alternating-current voltmeter was used to test the voltage at the instant of taking a photometer reading, both in the candle-power and illumination tests. The voltage was usually very steady. Five readings were taken at each test station.

In the results which are given later, the proper correction factors have been applied to reduce all results to what they would have been had the lamp used during the test been operated at 78.9 mean horizontal candle-power. This is the candle-power at which most American makers now rate 100-watt tungsten lamps of the type used when operated at the middle voltage marked on the lamp.

However, the watts per lumen for each test are given both on

the basis of 78.9 horizontal candle-power and 100 watts, which is the new rating, and 80 horizontal candle-power, 100 watts, which is the old rating. The reason for giving the watts per lumen, figured according to the old rating, as well as according to the new, is that considerable information has been published in the TRANSACTIONS based on the old rating of these tungsten lamps. The old rating is therefore given for purposes of comparison with previous results and to avoid any confusion between the new and old ratings.

The makers' rating of 773 lumens for a lamp of this type operated at 78.9 horizontal candle-power was accepted as correct in working out all the final results as to efficiency.

THE TESTS MADE.

The following different systems of lighting were tested.

A. Clear prismatic reflector over lamp at ceiling. The reflector used was 8 inches in diameter by 5¾ inches high and gives what is now commonly known as the extensive type of light distribution.

B. Bare unshaded lamp at ceiling.

C. Lamp at ceiling equipped with an opal bowl-shaped reflector, 8 inches in diameter by 6 inches high, giving the extensive type of distribution, but being somewhat more concentrating than the prismatic reflector used in test A. This opal reflector had 8 pairs of ribs. With this arrangement there was also made a test for the effect of shadows. After taking the regular reading for illumination without any shadow on the test plate, an 8-inch disk was placed 15 inches from the test plate and arranged at such an angle as to give the maximum possible shadow on the test plate. The idea of this test was partly to give a rough idea of how much of the light was received direct from the source and partly to determine how much reduction of illumination a person's head might cause were he necessarily seated so as to cast a shadow on his work. This is a matter which is principally of interest in connection with the lighting of offices without individual desk lamps.

D. Indirect lighting using a bell-shaped corrugated one-piece glass mirrored reflector of a type now very commonly used with

FOOT-CANDLES ON HORIZONTAL PLANE.

Station Number	Test A ft-c.	Test B ft-c.	Test C Unshaded ft-c.	Test C Shaded ft-c.	Test D Unshaded ft-c.	Test D Shaded ft-c.	Test E Unshaded ft-c.	Test E Shaded ft-c.	Test F ft-c.	Test G ft-c.
1	0.514	0.698	0.492	0.132	0.422	0.181	0.508	0.1905	0.673	0.528
2	0.891	1.070	0.904	0.150	0.619	0.320	0.790	0.3300	0.868	0.770
3	1.69	1.490	1.657	0.205	0.956	0.421	1.190	0.7220	1.28	1.084
4	2.44	1.840	2.400	0.237	1.307	0.508	1.586	0.8940	1.56	1.432
5	0.84	0.918	0.720	0.132	0.555	0.204	0.678	0.1980	0.767	0.690
6	1.82	1.473	1.682	0.240	1.09	0.406	1.270	0.3512	1.26	1.092
7	3.54	2.330	3.312	0.354	1.79	0.850	2.378	0.6900	2.046	2.000
8	4.48	2.960	5.440	0.436	2.49	1.67	3.36	0.9610	2.655	2.910
Average foot-candles	2.03	1.597	2.07	0.235	1.151	0.572	1.47	0.583	1.39	1.31
Lumens effective per lumens generated	52.0%	40.9%	53.0%	..	29.5	..	37.6%	..	35.6%	33.7%
Watts per lumen, new rating	0.249	0.316	0.244	..	0.44	..	0.344	..	0.364	0.384
Watts per lumen, old rating	0.245	0.312	0.240	..	0.432	..	0.339	..	0.360	0.38
Percentage reduction by shading	..	..	86.0	..	50.0	..	61.0	..	..	..

Test A—Prismatic reflector extensive type at ceiling.
Test B—Bare lamp at ceiling.
Test C—Opal reflector at ceiling.
Test D—Indirect lighting mirrored reflector.
Test E—Semi-indirect opal reflector pointed upward.
Test F—Roughed stalactite at ceiling.
Test G—8-inch opal ball at ceiling.

indirect lighting, classed by the makers as being of the distributing type. The top of the reflector was 16 inches from the ceiling. This reflector had been in use two years and was in good condition except for a slight blackening around the neck, probably caused by sulphur in the rubber covered lamp cord with which the fixture had been wired. This reflector is 9½ inches diameter by 4 inches deep and the lamp filament comes slightly above the level of the top of the reflector. The shadow test was also made at the various test stations with this system. As the source of light was the ceiling in this case as far as the test plate was concerned, the 8-inch disk which was used to shade the test plate was placed 15 inches from the test plate in such a position as to cast the maximum possible shadow on the test plate.

E. The opal bowl-shaped reflector used in test C was inverted so that the lamp was pointed toward the ceiling to produce a system of semi-indirect lighting. The top of the reflector was 14 inches from the ceiling. In this case the only direct lighting coming on the test plate was the much diffused light coming through the reflector. A considerable portion of the light received on the test plate was by reflection from the ceiling.

F. Over the lamp at the ceiling a stalactite enclosing globe was placed. This globe was 8 inches in diameter by 11 inches high and was roughed inside. It had seven pairs of ribs, which doubtless acted to some extent as refracting prisms, thus causing a slightly higher absorption than a plain roughed inside ball. This globe represents, or is typical of a considerable class of diffusing enclosing globes now in use with tungsten lamps.

G. An 8-inch opal ball was placed over the lamp at the ceiling. The opal was dense enough to produce complete diffusion so that the position of the lamp filament could not be seen.

NOTES AND COMMENTS.

In Fig. 2 are plotted curves showing the intensity in foot-candles at stations, 5, 6, 7 and 8. These curves fairly show the differences in uniformity of illumination with the different systems tested. On the left-hand side of Fig. 2 are the curves of

the illumination with the test plate unshaded. On the right-hand side are similar curves with the test plate shaded.

In measured efficiency the opal and prismatic reflectors with

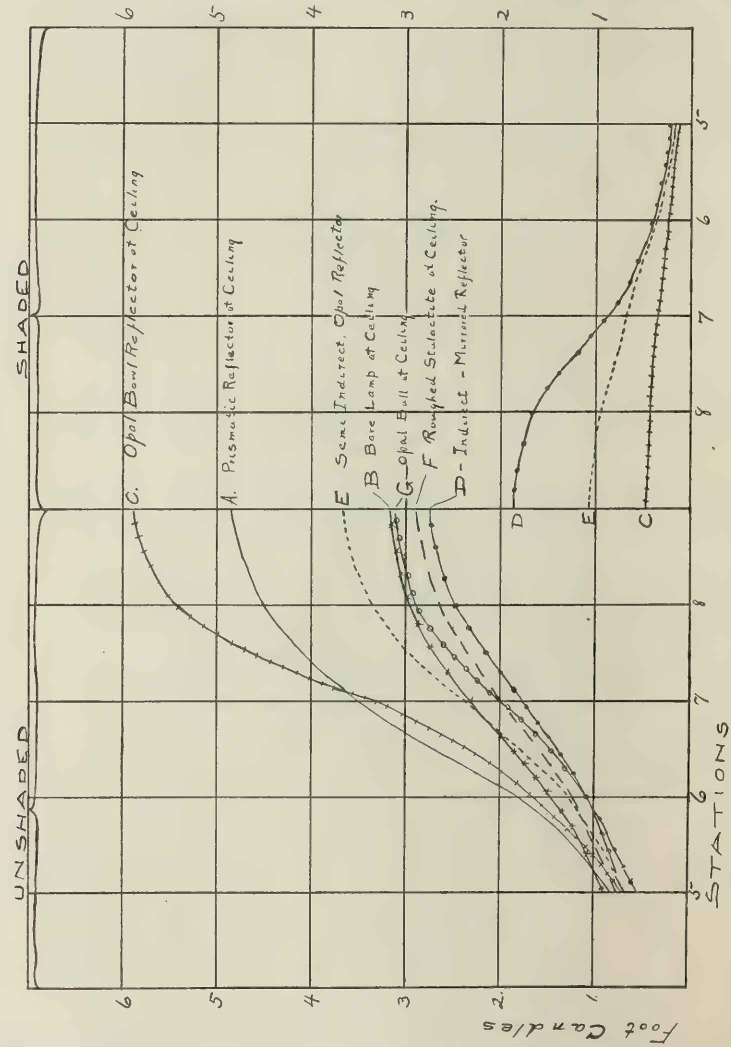


Fig. 2.

direct lighting naturally stand at the head of the list. This is because a larger percentage of the light is received direct from the lamp and reflector than in any of the other systems tested.

As regards the amount of shadow possible, these two most efficient systems stand at the bottom of the list, as might be expected, because when the direct light is cut off from the test plate there is a smaller percentage of indirect light to illuminate the plate.

As regards the relative comfort of the various systems tested to persons who may have to sit facing the center of the room, the indirect system heads the list followed by the semi-indirect, and the opal ball.

One interesting point is the small difference in efficiency between the opal ball which gives perfect diffusion of light over its surface, and the roughed stalactite which does not give nearly as good diffusion. On account of the greater absorption of opal as compared to roughed or etched glass, it would be expected that the results with the opal globe might show a much lower efficiency than with the roughed stalactite. That the difference in efficiency is less than one might expect from a consideration of the relative absorption of the two kinds of glass is probably to be accounted for mainly by the fact that the opal modifies the distribution of light from the bare lamp more than does the roughed glass. The result is that a larger percentage of the total light is directed downward and upward from the opal ball than from the roughed glass stalactite. That going downward reaches the working plane direct, and that directed upward toward the light colored ceiling is received back with one reflection on the test plane. With the roughed stalactite a larger percentage of the light is given off horizontally so it is lost by the absorption of the walls. From the standpoint of comfort the opal ball is preferable to the roughed glass, but even the opal ball with a 100-watt lamp in it is anything but comfortable to face in the center of such a small room.

The semi-indirect system with the opal reflector pointed upward is in my opinion far preferable to the opal ball, as it is not only easier on the eyes, but more efficient. The semi-indirect system may be said to occupy a place midway between the direct system using open reflectors and the indirect with opaque reflectors. It is not as comfortable as the indirect and it causes more pro-

nounced shadow, but it is more efficient and does not hide the source of light entirely where some light is wanted for decorative effects.

The results on indirect lighting in this test check very closely with results reported by the writer to this Society in 1909 in a somewhat similar room. In that paper certain conclusions were deducted from the best information available at that time. Some of these conclusions are confirmed by the tests now reported, but some need modification.

The conclusion from the present tests is that the ratio of measured efficiency between a direct system using efficient translucent reflectors and an efficient indirect system in a room of this kind is as the ratio of 3 to 5. What the practical working efficiency or "efficacy" of the two systems is for different purposes depends on the particular conditions and uses of the room. The present tests indicate that the measured efficiency of a direct system using enclosing globes is a little higher than an indirect system with opaque reflectors, although lower than a semi-indirect system with translucent reflectors.

In considering the objectionableness of shadows, it must be remembered that it is not altogether a question of the absolute amount of illumination obtained in the shadow, but rather of the contrast between the illumination in the shadow and the surrounding illumination. It is for this reason that the shadows with indirect illumination appear so much less than with direct illumination. Nevertheless the actual amount of shadow with indirect illumination as shown by these tests will doubtless be a surprise to many who have considered indirect illumination of this kind almost shadowless. While the shadows are far less than with direct illumination, it is far from being shadowless.

The writer wishes to express his appreciation of assistance rendered during these tests by Messrs. O. H. Caldwell and L. F. Payne.

DISCUSSION.

Mr. Albert Scheible:—May I ask Mr. Cravath whether in his statement regarding the placing of the lamp eight inches from the ceiling he means eight inches measured to the center of the filament?

Mr. Cravath:—Yes, that is to the center of the filament.

Mr. G. H. Stickney:—Mr. Cravath's tests are especially interesting in that they give actual quantitative values under certain well defined typical conditions. These are in contrast to many published tests where the conditions are not sufficiently defined to permit of reliable interpretation. While the tests give a good idea of the lighting produced and go as far as generality will permit, they do not give us the key to the relative utility of the illumination. This, of course, depends upon the purpose of the illumination.

A room of this size may be used for various purposes, but it would be used usually as a living room or an office. If it were used as an office, better results could be obtained by the use of two outlets rather than one; so that it is more typical of good living-room lighting. Considering it as such I would be inclined under the circumstances to prefer the semi-indirect system. Off hand, we are apt to give too much weight to measured efficiency. The great advance in efficiency which came with the tungsten filament has emphasized efficiency and there has been a tendency to go to the extreme in order to obtain the highest efficiency possible at the sacrifice of diffusion and other desirable qualities. The practice is now tending toward the other extreme of diffusion, although in general we have not yet reached the happy mean. To my mind, the lighting of a living room is more of an artistic problem than one of purely illuminating engineering, and the test of the suitability of the lighting should be the impression made upon the ladies of the household rather than the illumination measurements. The author has omitted to give us this information and I should like to ask him which lighting equipment was preferred by the ladies in his home.

Many of the accepted rules for ordinary lighting do not apply to household problems. For example, the most pleasant picture of home lighting that I remember includes a group of people sitting around a large fireplace with no other light than that from the burning log. We suffered no eye strain although we faced the flames, which must have produced some small degree of glare. Moreover, the light certainly was unsteady. Ordinarily we would say the light was coming from the wrong

direction, yet the result is an illumination, the pleasing effect of which is practically impossible to excel.

I hope Mr. Aldrich will tell us something about his extensive experiments in office lighting. He ought to be able to add considerably to our information on that subject.

Mr. T. H. Aldrich:—I cannot give the Society any information of value on office lighting at present as suggested by Mr. Stickney, as I have been unable as yet to make the illuminometer tests I intend to make on the different installations of office lighting which the International Harvester Company has made in its general offices.

Referring to Mr. Cravath's tests of residence lighting, which are very interesting, I might say that I have installed in my living room at home, size 14 ft. by 15 ft. by 9 ft. 6 in. high, a 100-watt unit with an opaque silvered reflector for indirect lighting, suspended 16 ins. from the ceiling. This scheme replaced a 4-light fixture, in which were used 25-watt tungsten lamps enclosed with suitable alabaster shades. The bottom of the shades measured 7 ft. 6 in. from the floor. I had observed that when two or four persons wished to read in different parts of the room that it was quite difficult to locate a chair properly so that sufficient light could be obtained in the right direction from the chandelier in order to read with comfort. The person sitting beneath the lights was about the only one who got the proper intensity for reading. I then added a student's double oil lamp. This I changed to electric and used a green porcelain 10-inch cone shade and a 25-watt frosted bowl tungsten lamp. This addition gave a good light for two people to read by when sitting around a table at one end of the room. I afterward replaced the tungsten lamps with 25-watt tantalum lamps and found a decided improvement in the lowering of the intensity of the light reflected on the book being read. The color of the tantalum filament gives a softer light for reading. The present 25-watt tungsten lamp is a little too bright for home use for close work unless enclosed. The color and intrinsic brilliancy is more harsh and trying on the eyes, especially if one is reading print on glossy paper.

After installing the indirect unit, one could sit in any part of

the room and read with comfort. Sufficient intensity was reflected from the ceiling to the plane of reading. From a reading standpoint I should say that the indirect lighting scheme was the easier on the eyes compared with the direct lighting. If the decorative effect is to be dwelt upon I should say a semi-indirect or a combination fixture of direct and indirect lighting would probably meet all requirements satisfactorily.

I should like to ask Mr. Cravath which lighting, in his opinion, is most satisfactory in that particular room for reading, considered from two or three different points in the room.

Mr. Cravath:—I should say the indirect, although there is not much difference between that and the semi-indirect. Some people are not used to completely hidden lights. For those the semi-indirect offers a visible light source with much reduced glare. Some of these systems which I tested were installed such a short time that I did not really test them in regular use. The system that has been the most popular in my house was an experiment which I tried; it is not there now, but it brought out enthusiasm from the feminine members of the household. It was a combination of direct and indirect, so arranged that none of the direct light could shine directly in the eyes, but gave a strongly concentrated light right under the fixture.

Mr. Scheible:—Mr. Cravath's paper contains a set of interesting figures and some good curves. I fear, however, that the curves may be misleading to some for the reason that the low ends of the curves do not start at the same point and therefore any attempt to show the uniformity or lack of uniformity of the illumination from the shape of the curves is apt to be misleading. In the curves, for instance, the lines F. and D. are very nearly parallel and yet the distribution factor for F., that is, the ratio of the highest foot-candle reading to the lowest, is only about 4, while for D it is 6.

Mr. Cravath:—The bare lamp makes the best uniformity showing of any of the systems, but it is intolerable because of its glare.

Mr. Arthur J. Sweet:—I notice Mr. Cravath, probably purposely, did not draw any conclusions on uniformity. The height of this particular room in the test, relative to the size of the

room, is not, I believe, thoroughly representative. We have many rooms in residences of similar type, and of about this size, but which I believe average, say, twelve inches higher than this particular room. The question of light versus the dimness of the room is extremely important. In the tests here considered, the opal reflector used as a direct light and the prismatic reflector would both show up better in uniformity and efficiency with a light suspended higher. It is a very poor comparison to make as long as this is the size of the room we are considering, and we should bear in mind that these particular factors do not necessarily apply to a room of different size.

I do not think that in home illumination the object is to produce a uniform illumination, which is usually the ideal in office illumination. On the other hand an uncontrolled non-uniformity is not desirable. That is, we wish to make our non-uniformity very definite. I believe the time will come in home illumination when we shall treat light and produce effects more as the painter produces effects with his brush. The most important effects can be produced by bringing out particular objects in a room by particular lighting of these objects. For instance, in a living room the table, which is logically the artistic center of the room, is the object which should be especially illuminated. Where the table is located in the center of the room the light can be concentrated down from the center of the room and produce very satisfactory effects. At least, I should like to express this view: different objects in the room should be illuminated in proportion to their artistic value or their logical importance in the scheme of the room.

Dr. M. G. Lloyd:—It is to be noticed in the table of measurements given that the highest efficiency accompanies the greatest range in the intensity of illumination and that in the case of lowest efficiency the range of illumination is also the least. The two sets of values go hand in hand through almost the entire set of measurements. If we disregard the artistic or decorative effects, the two principal considerations in designing illumination are efficiency and adequacy, or suitability to the purpose desired. Where general illumination is required the amount of power to

be utilized must be determined by the illumination in that part of the room where it is a minimum.

Now, according to these figures the differences in minimum illumination are very slight and consequently approximately the same wattage would be required for any of these methods which might be employed. Consequently, the very great differences in efficiency which are noted do not indicate any similar difference in the cost of lighting the room. The larger efficiencies merely indicate a surplus of illumination in those parts of the room which are most strongly illuminated, and this surplus may be regarded as a disadvantage rather than an advantage. In other words, the experiments cannot be construed as representing a more expensive scheme of lighting with the indirect or semi-indirect systems than with the others. That is, for the same minimum illumination the least efficient system is about as good as the most efficient, and if we consider the question of glare there would appear to be some advantage with the indirect or semi-indirect systems.

Mr. G. C. Keech:—The habits of a family regulate the position of light sources in different parts of a room more than anything else. A number of school children with books around the edge of a table in the center of the room will be taken care of very well by a central unit as suggested in this paper. If a musical family gathers around an upright piano at one end or in one corner of a room of this size, they will receive very little illumination, probably less than one foot-candle on the music, according to the measurements at stations 1 and 5.

As an illustration of a room where a central fixture is of very little benefit, I have in mind one with a couch projecting from one corner so that anyone reading in a reclining position requires light from the corner. Also anyone sitting at a lady's writing desk at one side of the om would cast a shadow on her work. A grand piano placed in another corner facing the center of the room would have shadows on the music cast from a central light by people sitting or standing in front. A small table in another corner where reading is done would not receive sufficient light from a central fixture without a very large wattage consumption in this fixture.

Although a believer in the use of large units in the ceiling, I think that this is a case which seems impossible to cover by a single central outlet.

Mr. Cravath:—I do not think Mr. Keech outlined any conditions in the living-room which he described which could not be taken care of by one, or at most two, central outlets equipped either for indirect lighting or semi-indirect lighting with the shadows reduced by dense diffusing glass. The room he describes would necessarily be considerably larger than ordinary rooms of the class considered in my paper. For the benefit of those who have not tried it, I may say that diffused lighting by reflection from central areas in a ceiling as in the case of the indirect and semi-indirect systems, makes possible lighting from much fewer outlets than equally satisfactory direct systems. In other words with diffused lighting we treat the illumination problem of the room as a whole. With direct lighting we may have to treat it piecemeal.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VI. MAY, 1911. NO. 5

COUNCIL NOTES.

The May meeting of the council was held in the general office on the 19th instant. Those present were A. E. Kennelly, president; V. R. Lansingh, treasurer; Preston S. Millar, general secretary; George S. Barrows, E. P. Hyde, W. H. Gartley, A. S. McAllister.

Reports were received and accepted from the secretary, the finance committee and several other standing and temporary committees.

In the report of the secretary the total membership of the society was given as 1,510. This number did not include any of the applications which had been received since the previous council meeting.

Eighteen applicants for membership were elected. One application for reinstatement was accepted.

Mr. J. R. Cravath of Chicago was appointed a director to fill the unexpired term of Mr. E. M. Lloyd, resigned.

A resolution was passed authorizing the publication of a pamphlet prescribing the general form for all papers submitted to the society for publication. The pamphlets will be ready shortly for distribution.

The names of three members, two resigned and one deceased, were withdrawn from the society's roll.

At the conclusion of the meeting a set of resolutions commending the course in illuminating engineering given at Johns Hopkins University last fall, under the auspices of the society and the university, was received. The resolutions are reproduced on the two following pages.

The Officers and Council of
The Illuminating Engineering Society,
New York City.

Gentlemen: At the close of the Special Course of Lectures on Illuminating Engineering given at The Johns Hopkins University under the joint auspices of The University and The Illuminating Engineering Society, a motion was unanimously passed expressing on the part of those attending the lectures, a hearty appreciation of the great educational value of the work presented and extending a vote of thanks to those responsible for the conception and presentation of this work.

We wish to congratulate you on your success in securing in this work the co-operation of The Johns Hopkins University, a University where graduate study is so strongly emphasized.

We believe that the lectures, which

treat of the subject of Illuminating Engineering in all its many phases, will be the basis for future instruction and reference and should be of the greatest benefit to all interested in Illuminating Engineering.

Respectfully,

George Harvey Jones Chicago.

John Bartleman Klumpp Philadelphia.

Henry Baldwin Dates Cleveland

Committee.

Baltimore, Maryland,
November 8th, 1910.

SECTION MEETINGS.

CHICAGO SECTION.

The Chicago section held a meeting Thursday evening, May 18th, in the new Peoples Gas Building. After an inspection of the lighting equipment of the building, the members assembled in the handsome main office on the first floor to listen to the reading of a paper by Mr. Charles A. Luther, entitled "The Illumination of the Peoples Gas Building." Messrs G. C. Keech, J. R. Cravath, O. R. Hogue, F. A. Vaughn and C. A. Luther were appointed a nominating committee to report at the June meeting a list of officers for the section for the ensuing year.

The concluding meeting of the season will be held Thursday noon, June 15th. Mr. W. D. Bradley will present a paper on "Natural Daylight Illumination."

NEW ENGLAND SECTION.

A meeting of the New England section was held May 9th. Dr. Louis Bell gave a talk on the "Chromatic Aberration of the Eye."

The last meeting of the season will be held June 12th.

NEW YORK SECTION.

Prof. R. S. Woodworth of Columbia University read a paper entitled "The Psychology of Light" at the meeting of the New York section which was held May 11th. The paper appears in this issue of the TRANSACTIONS.

The final meeting of the present season will be held in the United Engineering Societies' Building, June 8th. Mr Sydney W. Ashe will present two papers, one "A Corporation Graduate Course in Illuminating Engineering," the other on "A Comparison of Illuminants."

PHILADELPHIA SECTION.

The Philadelphia section held a meeting May 19th. Mr. G. H. Stickney, of the General Electric Company, presented a paper on "Mill Lighting." Seventy-five members and visitors were present.

Two papers will be presented at the last meeting of the season, June 16th. One of the papers, "Gas Ignition" will be read by Dr. Howard Lyon; the other entitled "Lighting a Garage by Electricity" will be presented by Mr. R. F. Zeek.

AN EXPERIMENTAL STUDY OF FLAME STANDARDS.[1]

BY E. C. CRITTENDEN.

At the 1910 convention of the Illuminating Engineering Society, a preliminary report of the work on flame standards of candle-power which is in progress at the Bureau of Standards was presented by Dr. E. B. Rosa and the present author. At that time it was expected that fuller details of the work would soon be published in the bulletin of the Bureau, but the pressure of other work has delayed such publication. In a paper on "The Pentane Lamp as a Primary Standard," presented at the Minneapolis meeting of the American Association, one phase of the subject was discussed, and the essential features of a new form of pentane lamp were described. In the present paper will be given some details of the earlier work and a few new facts which have developed since the first paper was written. As all the work has been carried on under the direction of Dr. Rosa and with the co-operation of other members of the Bureau staff, it is impossible to give proper credit to individuals for the various suggestions which have aided in advancing the work. At the outset, therefore the author desires to express his appreciation of the double privilege of speaking before the Society and of presenting a work for which he can claim but a fraction of the credit.

Sperm Candles and the Unit of Candle-Power—In the earlier papers mentioned, nothing was said about standard candles, and some inquiries have been received regarding the relative value of the standard candles now on the market and the International candle, in terms of which all lamps are certified by the Bureau of Standards. The question is of some importance because of the extensive use of the standard sperm candle as a basis for contracts and ordinance requirements. Numerous capable investigators have pointed out the wide variation in such candles, and to be at all valid any comparison with another standard must include observations on a very large number of candles. Moreover, it is admitted that to make the candles according to speci-

[1] A paper presented at a meeting of the Philadelphia section of the Illuminating Engineering Society, April 21, 1911.

fications is impracticable if not utterly impossible, and there is some reason to believe that improved processes of preparing the materials have resulted in changes in the intensity since their original introduction as standards.

In the excellent report of the committee on methods of taking candle-power of gas, submitted to the American Gas Institute in 1907, the situation is stated as follows:[1] "While there is no official manufacturer of the standard sperm candles, it is expected by the gas companies of this country that these candles shall be obtained from certain manufacturers in England, who are believed to make them as nearly as possible in exact conformity with the Notifications last issued by the Gas Referees in 1894." In connection with this, it is interesting to note the reply made to a large importing company by the English firm which supplied their candles, when a request was made for candles conforming to the referees' notifications. "The reply stated that the English standard candle manufacturers had endeavored to live up to those requirements and had found it impracticable to do so; that the candles had not improved in uniformity in consequence of the new method, and that, in short, the 'by-law was a dead letter.' "[2]

In brief, then, the standard candles on the market to-day have back of them no authority other than that of the manufacturers, who admit that they cannot make the candles according to specifications. In view of this, as well as the wide variations between different lots, it seems not worth while to devote the necessary amount of labor to make a direct determination of the relation between the average candle of the present day and the fixed unit, the International candle. However, when candles were still made under official supervision in England and the term "British Standard Candles" really meant what it said, a great deal of effort was expended to find a proper average value for such candles and to maintain this true unit by means of more constant standards. The Gas Referees and the National Physical Laboratory agreed that this unit was fairly represented by one-tenth of the intensity of their pentane lamps, and since 1898 the unit of candle-power called "British Candle" has been main-

[1] *Proc. Am. Gas. Inst.*, **2**, p. 473, 1907.

[2] Report cited, p. 508.

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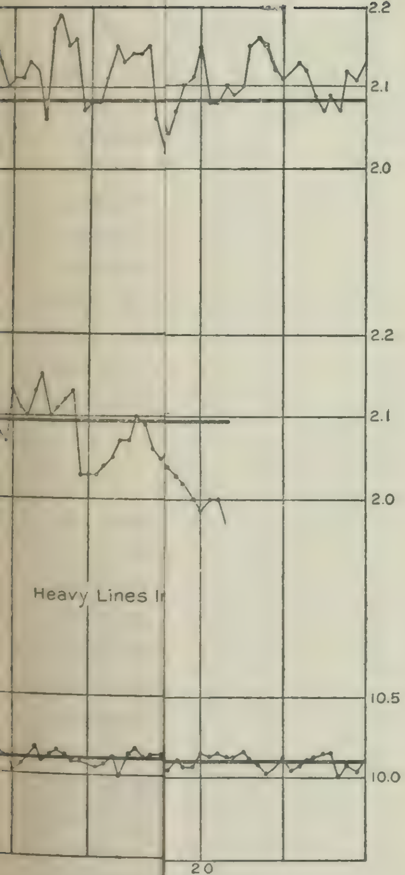

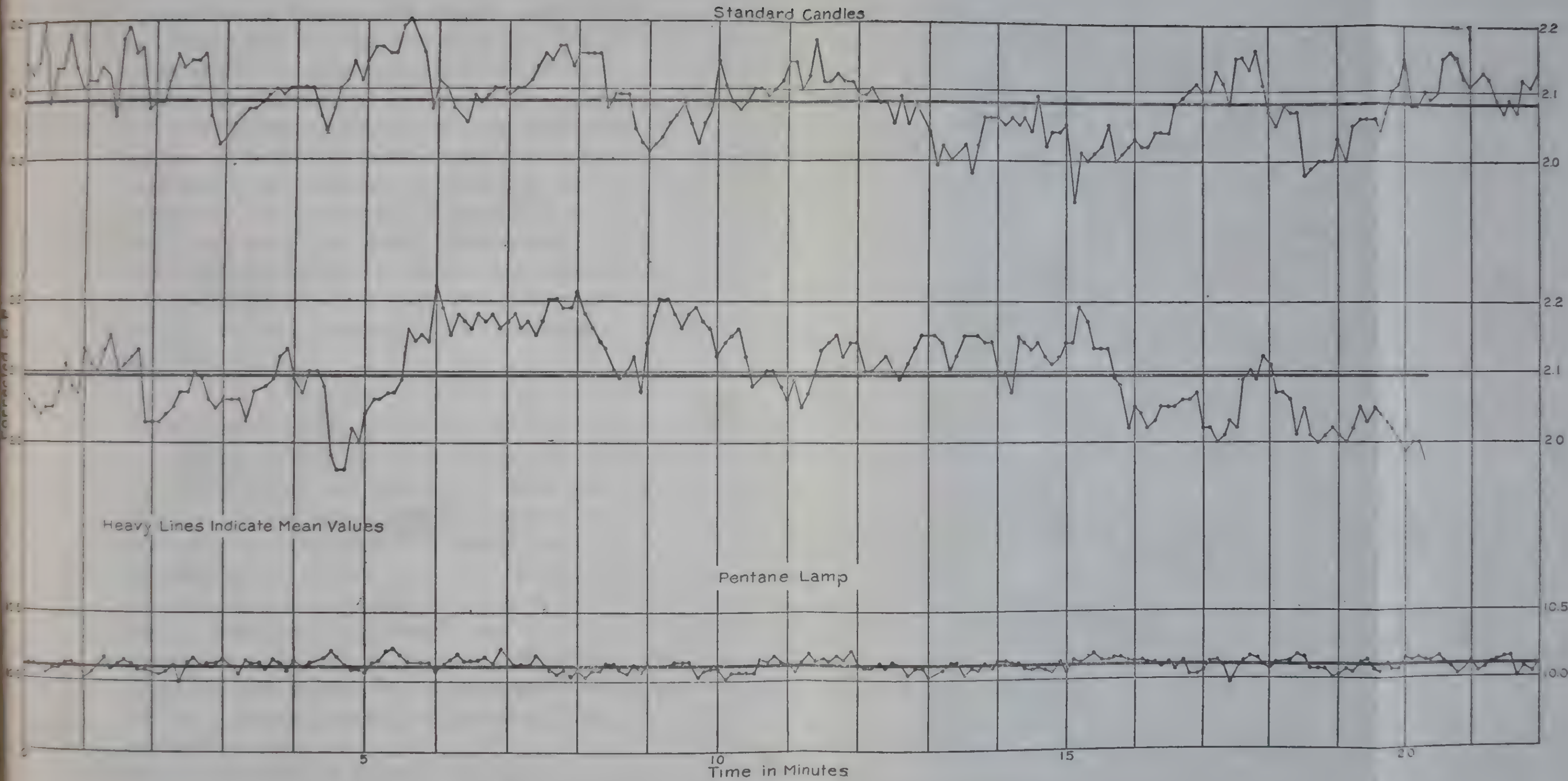

Fig. 1.—Flame intensity variations of standard candles and pentane lamp.

tained by these lamps and by electric standards calibrated from them. It has been found that some other pentane lamps differ from the original standards, but that does not affect the unit; it means simply that these other lamps are not strictly 10-cp. lamps. The International candle is identical with this unit, and is therefore, in England, the legally accepted average value of the old candle. The substitution of this unit for the uncertain sperm candle as a basis for legal obligations in this country is much to be desired.

Because of their simplicity and convenience, candles may well continue to be used for some kinds of work where only approximate results are required. A few tests of those now on the market have been made at the Bureau under different weather conditions; while not enough observations have been made to draw final conclusions, it appears that atmospheric conditions have more influence on them than on other standards. The tentative formula proposed by the committee of the American Gas Institute,

$$\text{C-p.} = 1 + 0.0087\ (9.3 - e)$$

where e represents liters of water vapor per cubic meter of dry air, appears to express very closely the effect of humidity. The factor 0.0087 and the normal water vapor 9.3 have been used for this correction, and the average corrected values for different pairs of candles have ranged from 1.94 to 2.10 c-p., a difference of about 8 per cent. The candles were obtained from two sources; one lot varied from 1.94 to 2.00 c-p. per pair, the average being 1.97; the other lot ran from 2.05 to 2.10 with an average of 2.08. That is, the unit derived from one lot would be 5.5 per cent. smaller than if based on the other lot, and there was no apparent reason for considering one better than the other.

Prof. Nichols[3] has recently recalled the records of variation in flames secured by Sharp and Matthews with a sensitive bolometric set-up, and for comparison (Fig. 1) it may be of interest to give the history of a pair of candles in a test as shown by the photometer with an automatic recording device. A series of readings on a pentane lamp taken in a similar way is also

[3] *Trans. Ill. Eng. Soc.*, 5, p. 846. 1910.

shown. The latter really indicates the errors of observation for such rapid readings rather than the variation of the lamp. The readings on the candles extended over 40 minutes: settings were made at approximately equal intervals, except when the candles flickered perceptibly as if stirred by slight drafts when no readings were taken.

The values plotted are corrected for moisture, and for sperm consumption by ten-minute periods. This particular curve happens to be for some candles of high intensity. Almost all the candles that have been tested have shown similar variations.

The Kerosene Standard—As a working standard the 5-cp. kerosene lamp is worthy of notice. Some difficulty may be met in keeping the chimney perfectly clean, and no small degree of skill and patience is necessary in trimming the wick to get a good flame; but if these two points are carefully looked after, and good oil is used, the lamp will usually maintain its value constant within a fraction of one per cent. through a whole day. If heavy oil is used, a redder flame is produced, and although the initial candle-power is not seriously affected, a greater drop is likely to occur during the day.

Not only will the lamp maintain its value during a day, but the experience of the author leads him to believe that it is possible to make it repeat day after day with a variation considerably smaller than that of the candles which are usually used for its calibration. This reproducibility of intensity can be improved by a slight modification in the operation of the regular Elliott lamp. When the lamp is operated according to the directions furnished with it, the intensity varies rapidly with height of flame, the candle-power running up as the flame is turned higher. Since the flame is seldom perfectly straight along the top, it is difficult to tell when it is at exactly the right height, and consequently variations are introduced. It happens, however, that if the slot in the screen is cut a little lower than in the lamp as regularly furnished, or if the flame is set more than the specified quarter inch above the top of the slot, a certain height of flame can be found so that the candle-power is a maximum and small variations in the height do not make so much difference. Of course, if the lamp is to be used as an independent working standard

without daily checking, one should take at least two or preferably three settings of the flame for each measurement. As an illustration of the degree of accuracy which may be obtained by using the lamp in this way, some measurements made last summer in comparing oils are given below, including only those in which the same oil was used. The slots in the screens were of slightly different shapes and sizes, so that the absolute candle-powers have no significance.

TABLE I.—CANDLE-POWER OF ELLIOTT KEROSENE STANDARD LAMPS.

Series	No. of sets	Aver. c-p.	Average deviation C-p.	Average deviation Per cent.	Highest c-p.	Lowest c-p.
			Lamp B. S. 6348.			
1	18	5.11	0.043	0.8	5.23	5.01
2	11	5.12	0.025	0.5	5.16	5.08
3	12	5.15	0.036	0.7	5.20	5.06
			Lamp B. S. 6800.			
1	18	4.98	0.038	0.8	5.09	4.90
2	11	4.99	0.033	0.7	5.05	4.95
3	12	5.04	0.044	0.9	5.10	4.94
			Lamp B. S. 6966.			
1	15	4.59	0.032	0.7	4.65	4.53
2	10	4.62	0.030	0.65	4.68	4.57
3	9	4.59	0.057	1.2	4.68	4.48

It is noteworthy that if the candle-power of the individual lamps is taken as determined by the mean of the three series, only two single measurements out of the 116 differed from the mean for the particular lamp by more than 2 per cent.

The kerosene lamp has also the great advantages that it is very steady, is practically unaffected by any ordinary draft, and that it can be used in any kind of weather. In fact many of the measurements tabulated above were made at times when the high temperature made satisfactory work with other flame standards very difficult. Moreover, in color it approaches the ordinary illuminants. As measured by the Ives colorimeter the values given in Table II. have been found for the several standards in terms of the 4-watt-per-candle carbon lamp, with which a flat coal gas flame is almost identical in color. As another method of showing relative color values, there is given in the fifth column the approximate voltage at which a given carbon comparison lamp has been found to match the various flames in

color. In the case of the kerosene lamp the color varies considerably with the height of the flame.

TABLE II.—COLOR VALUES OF FLAME STANDARDS.

	Ives Colorimeter Red	Ives Colorimeter Green	Ives Colorimeter Blue	Comparison voltage
4-w. p. c. carbon lamp				
coal gas (flat flame)..	100	100	100	107
Kerosene standard—				
Light oil	100	101	102	108
Heavy oil	100	96	85	100
Carcel lamp	100	94	76	96
Pentane lamp..........	100	91	68	91
Candles	100	88	61	87
Hefner lamp	100	87.5	59	86

The effect of water vapor on the kerosene lamp is practically the same as on the Hefner and the pentane lamps. One set of measurements illustrating this is plotted in Fig. 2.

There are two uses for which the kerosene standard is very

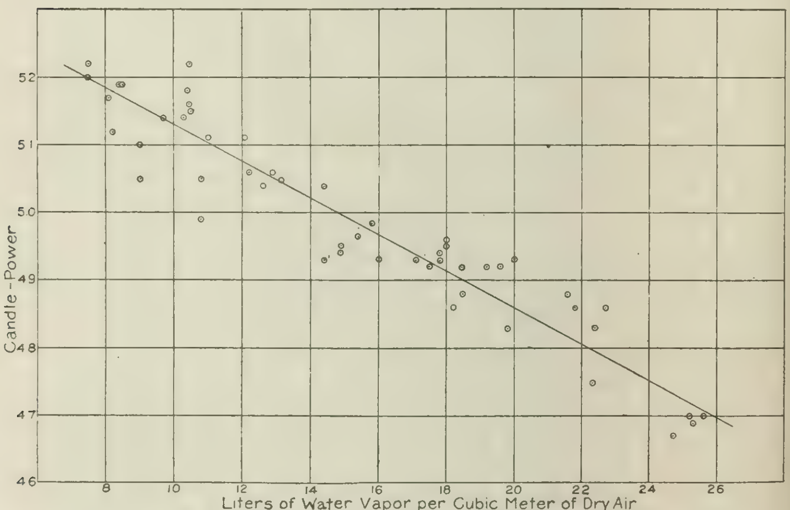

Fig. 2.—Variation of candle-power of an Elliott kerosene lamp due to moisture.

well suited. One is in tests where the highest degree of accuracy is not required and where the results are not likely to form the basis of controversy; in such cases a kerosene lamp, previously calibrated, is at least as good as candles and has the great advantage over them of requiring no attention during the actual photometric

work The other application is as a comparison lamp to be left unchanged at one end of the photometer bar, while the real standard and the light to be measured are alternately introduced at the other end. The advantages of this method of substitution are too well known to need discussion and the kerosene lamp makes it easy to obtain all these advantages in the ordinary photometer room.

The Hefner Lamp—As a working standard, the Hefner has three defects which, in combination, almost prohibit its use. These are, its unsteadiness, its color, and its low intensity. Considerable thought has been given to the problem of removing these difficulties without losing the good features of the lamp. The flame can be made steady by using a thicker wick-tube, and Hefner-Alteneck has himself suggested this change; but the thick tube has a cooling effect which reduces the candle-power and at the same time makes it necessary for the wick to project out of the tube, which is very undesirable. Other fuels which might be used were investigated rather thoroughly by Hefner-Alteneck, but none better than amyl-acetate was found. A mixture of benzol and alcohol has been suggested. It, however, affords no advantages. If the proportion of benzol is small (below 16 per cent.), the color is better than that of the amyl-acetate flame, but the intensity is less. The addition of more benzol increases the intensity somewhat, and at the same time makes the flame redder. Both color and intensity can be improved by the use of a chimney; but this changes the character of the lamp entirely and the advantages to be gained do not seem to be sufficient to justify such a development.

In brief, the one practical suggestion of possible adaptation of the Hefner which has resulted from the present work is that of making it give one International candle by setting the flame at a height of 45 millimeters.

In the work previously reported, three lamps with Krüss sights were measured at 45 mm. flame height by putting a ring 5 mm. thick beneath the base of the regular sights, and values of 0.9975, 1.000 and 1.002 respectively were obtained. Three lamps with Krüss sights adjusted to 45 mm. have since been sent to the Bureau by a German maker. Not enough measurements

have been made on them to give them reliable values, but the means of the ten measurements made give 1.002, 1.003 and 1.005 International candles as respective values for the lamps.

In this connection it may be said that some difficulty is experienced in obtaining amyl-acetate which will exactly meet the requirements of precise testing. Of five lots purchased, all passed all tests except the specification that 90 per cent. shall distill over between 137° and 143° C., but only one lot fulfilled this requirement. The photogenic values, however, apparently differ by not more than one per cent.

The Pentane Lamp as a Secondary Standard.—The results already published have indicated that for a working standard a calibrated pentane lamp is probably the most reliable of flame standards. The variations from time to time of an individual lamp properly used are such as may be safely neglected when the lights to be measured are flames; and if the actual intensity is desired, corrections for moisture and barometric pressure can be made.

It appears possible that temperature might be a third cause of variation, especially because the proportions of air and pentane vapor fed to the flame certainly do depend somewhat upon the room temperature. Mr. Walter Grafton[1] of London made a long series of measurements on gas, using a pentane lamp on which the saturator was kept at fixed temperatures in a water-bath. The values found for the gas showed that when the saturator was kept at 52° F. the candle-power of the standard was over 3 per cent. higher than when the saturator was at 92° F. Probably a large part of this variation was due to the cooling of the lamp standard, which would affect the air supply. It is true that cooling the saturator alone below 10° C. (50° F.) does increase the intensity by more than 1 per cent., at the same time making the flame whiter, as would be expected since the proportion of air in the vapor is larger; but the greater part of this change occurs below 15° C. Such experiments have not much bearing on the question, because the temperature in the laboratory or testing room is not likely to be below 15° C., and even if the room is cool the saturator on the lamp is warm. It is more to the point, therefore, to consider measurements made

[1] *Journ. of Gas Ltg.*, **82**, p. 771, 1903.

with the lamp in normal condition. The determination of a temperature correction would be somewhat complicated by the fact that large changes of temperature are usually accompanied by variations of water vapor in the air, and the so-called humidity correction might really represent the combined effect of moisture and temperature change. That this is not true, however, is indicated by the fact that the humidity corrections determined for a number of lamps are the same, although the range of temperature during the observations was in some cases fifteen Centigrade degrees and in others only three degrees. The candle-power values corrected for the barometer and humidity seem to be entirely independent of temperature variation within the laboratory range.

Another possible source of trouble is the fuel. In the earlier report considerable emphasis was placed on the effects of fractionation in the saturator. It is impracticable to keep the pentane in the lamp within the limits of density prescribed for fresh pentane, that is 0.6235 to 0.626; the practice adopted has been not to use pentane after its density reaches 0.635. The change in intensity of the flame caused by the fractionation of the fuel depends considerably on the purity of the original supply, for as the process goes on the heavier impurities become concentrated, the boiling-point of the mixture rises rather rapidly, and more and more of the impurities are carried over to the flame. So far as practical testing is concerned, however, no alarm need be felt over this difficulty, for if ordinary care is exercised in avoiding the collection of residues in the saturator the changes arising from fractionation are considerably less than one per cent. In fact, the variations caused by poor pentane are smaller than might be expected. The worst sample that has come to the Bureau had a density of 0.641 and the chemical test showed the presence of considerable quantities of impurities, yet the candle-power produced was only 1.25 per cent. too high. Two other factors which may cause variation in a given lamp should be mentioned. First, drafts: the photometer room must be well ventilated, but no direct drafts should reach the lamp. It is not sufficient to ensure that the drafts do not disturb the flame; the effect on other parts of the lamp may be appreciable in ways to be discussed later. The second factor is

the gauge for setting the chimney: this should be checked from time to time. Some gauges have been found to shrink more than one per cent., involving the same percentage change in candle-power, and most of them change somewhat with time. The practice of making them of wood or fiber is bad; metal should be used.

Differences Between Pentane Lamps—The variations which have been mentioned are those which have to be considered in using the pentane lamp as a working standard, after calibration. There is another class of variations which do not affect such use of the lamp, but which are vitally important if the lamp is to be considered as a primary standard. These are the differences between different lamps burning under the same conditions. In the former paper this difference was shown to be as great as 2.5 per cent. between certain English lamps, while American lamps showed similar variations, most of them running low.

It has been pointed out that the specifications are not strict enough in regard to the dimensions of the burner openings which supply the vapor to the flame. Of the three English lamps tested all fulfill the specifications in this respect, and all have the individual holes about the same size (1.35 mm. in diameter), but in the one which gave the low candle-power the diameter of the circle of holes was 2 per cent. smaller than in others. This was thought to be a possible explanation of the low value, but it has since been found that the effect on the candle-power does not exceed 0.5 per cent. A series of interchangeable burners, in which the variations were made even greater than the specifications permit, have been tested. In these the outer diameter of the circle of holes varies by 4 per cent. and the different burners have holes ranging from 1.1 mm. to 1.5 mm. in diameter. The combined effect of variation in holes and in size of circle is only about one per cent. in candle-power. The reason that this effect is so small is probably to be found in the fact that the pressure on the vapor is very small, and the flow from the holes is so gentle that the vapor spreads so as to cover the whole top of the burner. Consequently the size of the flame is determined more by the size and shape of the top of the burner than by the dimensions and location of the holes in it. Still a closer

specification of the latter would remove a source of small differences between lamps.

A far more serious cause of difference, and the one to which the low values of American lamps is largely due, is suggested by a study of the heating curves of the various lamps.[1] The longer time required for the American lamps to reach a steady condition is not satisfactorily explained by their heavier construction. Moreover, the form of the curves indicates the presence of two opposing influences, one tending to make the candle-power high, and the other, which becomes effective a little later, tending to lower the candle-power. In the American lamp this second effect is greater than in the English form. These two opposing influences are simply the temperatures of the two columns which constitute the circulatory air system of the lamp. The chimney becomes hot first and a vigorous circulation is set up, making a strong draft up through the burner and thus broadening the flame. As the lamp standard, through which the air flows down, becomes warmer, the temperature difference of the two columns is less; the circulation is less vigorous, and the flame becomes slightly narrower.

Beneath the saturator is a flat radiating plate, which in the English lamp is brazed to the standard and serves to conduct heat away, thus keeping down the temperature of the down-flowing air. In the American lamps this plate has been considered primarily as a support for the saturator, and is connected to the standard only by two bands. It therefore fails to function properly as a radiator of heat; the standard becomes hot, the air flow is decreased, and the candle-power is lowered. The substitution of a brazed plate for the loose one increases the candle-power by about one per cent., while freeing the plate from the standard, even without removing it entirely from the lamp, causes a reduction of over one per cent. In the experiments performed, the same American lamps gave 9.63 candles when the plate was not in contact with the standard and 9.75 in the regular condition. This suggests the possibility of an appreciable variation being introduced by accidental change of the contact between the plate and the standard. For this reason as

[1] *Trans. Ill. Eng. Soc.*, 5, p. 764, 1910.

well as to bring the lamps nearer to 10 candle-power, the brazed plate should be used.

Another detail of construction which makes about 1 per cent. difference in the same way is the connection between the bottom of the chimney and the standard. This should be of non-conducting material, but in the American lamps it has been made of metal, which conducts heat across to the standard and thereby reduces the candle-power. When these two faults of construction are remedied, the American lamp will give very close to 10 candle-power and will reach a steady state in about 20 minutes after lighting.

By interchanging parts so far as possible, evidence has been obtained that the discrepancy between the English lamps studied is largely due to some difference in the air system, but, unfortunately for this work, the lamps are not intended to be taken apart and the parts are not interchangeable in general. Consequently the exact cause of the difference has not been found.

The candle-power of a pentane lamp can be appreciably increased by any method of cooling the standard. Even the introduction of a screen to cut off the radiation of heat from the flame to the standard makes a perceptible difference, and drafts of air blowing over the lamp probably produce more effect through the disturbance of temperature conditions than by disturbing the flame directly. Precautions should therefore be taken to obtain a gentle and regular flow of air past the lamp when it is in use.

It has been said that the modified American lamps will give practically 10 candle-power, although the best English lamps that the Bureau has been able to obtain have had a value of only 9.92 candle-power, as determined by the National Physical Laboratory of Great Britain, and slightly below 9.9 as measured here, for there is one feature which tends to make the American lamp higher in candle-power. This is the method of supporting the inner chimney. The chimney is set, when cold, 47 mm. above the burner, but the expansion on heating reduces the height. Since the chimney is supported near the bottom in the American lamp and at the top in the English, the reduction in height is less in the former type. The actual height when the lamps are burning has been found to be 46.7 mm. in one American lamp.

and 45.9, 45.8 and 45.7 mm., respectively, in three English lamps. Incidentally, these variations suggest that if the lamp is to be a primary standard, some better method of fixing the height is desirable.

A New Form of Pentane Lamp.—The Harcourt pentane lamp was developed to meet the requirements of gas testing and has met with deserved success in that work, but it cannot be considered a good primary standard. The fact that British makers do not succeed in reproducing the 10-cp. lamp is *prima facie* evidence of vital weakness in this respect, and has led the electrical interests of Great Britain to take one particular lamp at the National Physical Laboratory as the standard.

The apparatus which serves to realize a fundamental unit of any kind should be made up of standardized, reproducible and interchangeable parts. It is possible to make lamps similar to the regular Harcourt type, or the American form, which would meet this requirement, but at best the two essential factors, the fuel and the air supply, are largely beyond control in such lamps. The variation in the composition of the vaporized fuel with temperature of the room has been mentioned above. This difficulty is largely theoretical, for in practice the effect is really negligible, especially as the temperature of operation might well be defined for a primary standard. The air circulation, on the other hand, presents very serious practical difficulties, since it is so sensitive to temperature variations in the lamp, which in turn may arise from conditions that are difficult to control.

It has therefore seemed worth while to develop a lamp in which the fuel and the air supply may be entirely under the control of the operator. Instead of depending on the supply of heat from the flame, electric heating has been used to vaporize the pentane and to set up the draft through the burner. Incidentally, this allows the design to be made much more compact and symmetrical. The lamp is in the experimental stage as yet, but in some respects it appears so promising that it may be well to set forth the ideas on which it is based, and some of the difficulties to be met.

The pentane is placed in a closed reservoir beneath the burner, with an insulating coating so that the heat for evaporation is supplied almost entirely by a coil of wire of known resistance

through which a measured current is sent. This coil is placed above the liquid, being wound over a wick which reaches down into the pentane. This arrangement seems to produce steadier evaporation and possibly less fractionation than a coil immersed in the pentane. An auxiliary coil serves to warm the liquid when starting. The closed and insulated reservoir, besides furnishing a vapor always free from air, has the advantage that in the temperature and the energy necessary to vaporize the required amount of fuel one has constantly two checks on the quality of the pentane, and the range of density to be used can be fixed as closely as one chooses. In one lamp for example, starting with the regular quantity of pentane (about one-sixth of a gallon), of density 0.625 and of very good quality, the temperature of the vapor necessary to make the flame the proper height is about 26° C. For two hours the rise is very slow, amounting in all to 2°, while the power supplied has to be increased only about 2 per cent. In another two hours the rise of temperature will be between 3° and 4°, and the rate of energy supply must be increased by 8 per cent. more. In the four hours, the density of the liquid rises to about 0.635. During a third period of two hours the density increases more rapidly, the temperature of the vapor rises some 6°, and the heat of vaporization runs up about 15 per cent. This accelerated rate of change is largely due, of course, to the decrease in the quantity of liquid in the reservoir, since the six hours burning consumes at least two-thirds of the original supply. If there is a change of candle-power accompanying this amount of change in the fuel when good pentane is used, it is so small that it has not been detected.

Although the above method of supplying fuel to the burner has advantages, it presents a difficulty which as yet more than counterbalances them. This is that the feed is not as steady as that furnished by the gravity flow of the Harcourt lamp in which both ends of the system are open to the atmosphere. With the closed reservoir, the supply of vapor is apparently made irregular by two kinds of disturbances: first, mechanical jar causes a variation of the rate of evaporation; second, the excess of the pressure in the reservoir over that of the atmosphere is exceedingly small, so that the fluctuations which occur in the air pressure are large compared to the differential pres-

sure. To remedy these troubles the reservoir must be able to equalize pressures readily with the outside without much change in the flow of vapor through the burner. Several devices are available, the simplest being an open tube on the reservoir. No pentane need escape through it, for because of its high density the vapor will not rise far. Another plan is to have at any one time only a small volume of gas beneath the burner, which can be attained either by making the reservoir small, or by providing a chamber beneath the burner into which fuel is fed through a small opening from the main reservoir. The latter may then be at relatively high pressure. A number of modifications have been tried, but so far nothing equal in steadiness to the old gravity feed has been found. Fortunately, as has been mentioned above, the objections to that method of fuel supply are based more on what might happen than on what does. The reliability of the lamp would not really be much improved by changing the method of feeding the flame.

The air system of the Harcourt lamp is more objectionable. It is certain that in it lies one of the greatest obstacles to reproducibility. It is therefore especially gratifying that in the experiments so far made, the method of electrical control of the air has proven markedly successful. A short vertical tube jacketed outside, and with a heating coil inside, is connected by two 45 degree joints into the side of the burner chamber and thence up through to the center of the burner. The strength of the draft up through the burner is then readily varied through wide limits by regulating the supply of energy to the heating coil. A stronger draft causes a broadening of the cone of the flame, with a corresponding rise in candle-power. The practical limit is fixed by the decreasing steadiness of the flame as the draft becomes too vigorous. The question now is to determine the best device for fuel supply to accompany the electrical regulation of the air. It will then remain to draw exact specifications, to determine how well one lamp can be made to repeat its values under specified conditions, and especially how closely a number of similar lamps will agree. It is hoped that in course of time a real primary standard can be developed which may afford a valuable check on the unit of light as maintained by the present excellent electric standards. The new form of lamp

is, of course, not intended to displace the Harcourt lamp as a working standard. The Bureau of Standards will continue its efforts to acquire information which may help in improving the construction and the use of that lamp, which, as was said before, seems to be, when calibrated, the most reliable and practical of flame standards.

It was stated in the beginning that this paper is based on cooperative work. The paper would be incomplete without an expression of the author's obligations especially to Dr. Rosa and to Mr. A. H. Taylor, who have assisted throughout the work. He is also indebted to Mr. R. S. McBride for preparation and testing of fuels, and to Mr. G. J. Schladt for assistance in the later part of the investigation.

DISCUSSION.

W. J. Serrill:—What should be the practice of a small or medium-sized gas company in determining candle-power. In these days of commissions, it is often of more or less importance to determine with accuracy the candle-power of the gas. Mr. Crittenden has shown, that compared with candles, readings taken from the pentane lamp give more accurate results. Suppose a small company were to use a pentane lamp, say for two or three years, without checking it during that time; would it be apt to get as accurate results as with the candles, or would the value of the lamp be apt to change widely?

Mr. Crittenden:—From experience I should say that if it is handled with reasonable care, a lamp once standardized is not likely to change to any such extent as different lots of candles will differ. With a lamp of the present American type, a slight accident might vary the contact of the radiating plate with the standard, and a difference of one or two per cent. might result. For this reason the plate should be permanently and securely fastened. There is, of course, the possibility of variation caused by the finish of the lamp, which would cause the temperature relations to vary somewhat. In fact, Professor Paterson of England has made a definite statement that the lamps gradually change during the first few months of use, and increase as much as 0.7 per cent. in value. The London Gas Referees who have pursued similar lines of investigation have not found any such

change. I am of the opinion that a pentane lamp once standardized and properly used, under conditions similar to those in which it was standardized, should not show any change approaching 1 per cent. Some difference must be expected, however, in the values obtained by various laboratories, because it is difficult to reproduce conditions exactly. Between the two lots of candles mentioned, there was a difference of as much as 5 per cent. Certainly one would not get any such change as that with a pentane lamp.

As to the advisability of a small gas company buying a pentane lamp; that would depend upon circumstances. As a matter of general principle, in order to avoid controversy, where differences of opinion regarding candle-power might arise, I suppose it would be well to do so.

Geo. S. Barrows:—I should like to ask Mr. Crittenden whether a correction could be made which would do away with the peak of the curve which he exhibited, if a thermometer were placed in the annular space in the rising current of air and another thermometer in the descending current of air and the difference in readings noted.

Mr. Crittenden:—It is not practicable, I believe, to do that, though it may be possible. The temperature curves show that the lamp does not attain exact temperature equilibrium in less than one hour. In lamps with radiating plates brazed on, the flame, however, reached a constant value within twenty minutes. Ordinarily it is good practice to wait until the lamp has reached this constant condition.

Mr. C. O. Bond:—I wish to ask, in reference to the statement that Mr. Crittenden attributed to Mr. Paterson, that pentane lamps in use for fifteen months increase in value 0.7 per cent., whether the change is due to the fact that the chimney is supported from the top and the heat being maintained in the standard for a considerable length of time; and whether the chimney does not after a while acquire a permanent "set"?

One other point: would not the variation in value of pentane lamps be partially accounted for by the fact that their castings are not all of the same construction?

Mr. Crittenden also mentioned that one of three English lamps

showed a difference due to air variation. I know that in the American lamps, the interior of the casting was not always as smooth as it should be. Differences in air flow might be caused by unequal internal friction.

Mr. Crittenden:—I am sure Mr. Bond's idea is an ingenious one; that of a permanent "set" of the chimney, which would mean less expansion in an old chimney. However, nobody else has found the change that Paterson mentions.

As to the suggestion in regard to the bottom of the burner, I think this variation of castings is just the basis of the whole difficulty. The lamps should be made interchangeable, and those parts should not be irregular in size.

Mr. Barrows:—It seems to me possible that the surface of the inner chimney directly over the lamp, being heated as constantly as it is, would become more or less affected by the products of combustion. The descending flue will probably not become affected very rapidly, but possibly the radiating value of the inner chimney above the flame will be materially affected by the material of the surface. If the surface were of porcelain, or glass, or something of that sort, one might get more constant results.

Mr. Bond:—I am glad that Mr. Barrows raised that point. I remember talking with Dr. Harcourt about that very point, and in examining some of these lamps in a laboratory we found that the outer painted surface of the inner chimney peeled off and left a bright metallic surface, which might make a difference in value. Dr. Harcourt stated that the effect of a stand-tube which had become polished through much handling was considerable. He said that the constant radiating quality of this tube was an important factor in constancy of the standard.

Mr. Crittenden:—Have you experimented at all in that direction; have you tried the effect of blackening the inner chimney from which the paint had peeled, for instance?

Mr. Bond:—I will refer that to Mr. Kelley.

Mr. J. P. Kelley:—The effect on the candle-power when two flame standards were opposed, was not noticeable; but I think that this point should be verified in a test where very accurate control is possible, as at the Bureau of Standards.

Mr. Crittenden:—We have had some experience in that line arising from the fact that some makers have used very poor

paint. In two lamps sent to us which had never been lighted, all the black paint came off the inner chimney as soon as the lamps were lighted, and we took the opportunity to study the effect. We were not able to find any difference by having the inner chimney either bright or black. The reason is, probably, that the heat was transferred from the inner chimney to the air around it, not so much by radiation as by conduction, in which the character of the surface is less important. With the outer chimney polished, the lamps appear to give a slightly higher value.

Mr. Serrill:—Mr. Crittenden has shown that some very good results can be obtained with the Elliott kerosene standard; can it be depended upon with reasonable accuracy by a small gas works? How does the cost compare with other standards?

Mr. Crittenden:—It costs $25.00, and the pentane lamp costs from $75 to $80. Moreover, the kerosene lamp is less expensive to maintain, and can be used in all sorts of climates; for instance, in the South, where a pentane lamp could not well be used on account of the high temperature. The kerosene standard is suitable for tests which are made for information, and not as a basis for contracts. If care is exercised in the trimming of the wick, one can secure fairly consistent values from day to day.

Mr. Kelley:—I should like to ask if it makes any difference whether a rubber tube or a metal tube is used in the American lamp?

Mr. Crittenden:—We have not changed on the same lamp from the rubber to the metal tube, but I do not know of any reason why it should make any difference. There are at least four ways in which the lamp may be regulated. According to the directions of the Gas Refereees in London, the flame should be set by varying the opening at the inlet of the saturator. This cock controls the air. Another way is to regulate by the cock at the outlet of the saturator. Still another way, is by having a pinch-cock on the rubber tube, and this is the method we have followed oftener than any other. Another way is by putting a tube on the saturator inlet, and a pinch-cock on that. Of these four ways of regulating the lamp, it apparently makes no

difference which one is used. It would seem then that it does not matter whether a rubber tube or a metal tube is used, provided that the rubber be saturated with pentane and the metal tube be large enough to allow as free a flow as the rubber, and warm enough to prevent condensation.

Mr. Bond:—I would like to ask if it would not be feasible to construct a pentane lamp of say 5 candle-power in value, to be otherwise similar in appearance to the larger 10-cp. lamp, only more portable?

Mr. Crittenden:—I see no reason why it could not be done. There might also be some advantage in reducing the size of the flame, which would make it easier to maintain constant.

I neglected to call attention to the ingenious scheme used by Harcourt for getting constant values and reducing personal error in setting the flame. The greater part of the light is furnished by the upper two-thirds of the flame. If the flame is turned higher, there will be less light from the lower portion, while on the other hand the more luminous upper part becomes a little broader. Therefore, over a considerable range in the height of flame, there is very little change in candle-power. In standardization an attempt is made to set the flame at the height which gives the maximum value.

THE PSYCHOLOGY OF LIGHT.

BY PROF. R. S. WOODWORTH.

In a strictly logical division of the science of light, what concerns the purely objective processes would be assigned to physics, to physiology whatever concerns the action of the retina and its nervous connections, and to psychology the sensations of light and the utilization of light in perceptions and various other mental performances. Any such division of the field is, however, artificial; for the physicist and physiologist have to approach their objects of study through the medium of sensations and perceptions, and they have accordingly been among the foremost contributors to what is theoretically the psychology of the subject. Moreover, the psychologist gains nothing by attempting to keep his treatment purely psychological; for what one wants to know is facts in their relations rather than facts in isolation. Consequently the psychology of light, as it is usually presented, contains much that might equally well be brought forward by the physicist or, especially, by the physiologist.

It may be said, however, that the psychologist starts, by preference, where the others start from necessity—namely, from sensations and perceptions of light. Suppose that, without knowing anything of the physics of light, one has at his disposal an abundance of bright, dark and colored objects of every shade and hue, and preferably of the same sort of material, such as paper or silk. The observer of such a collection of objects not only sees a great variety of colors, but he easily notes degrees of resemblance among them, and is able to divide them into groups, or, still better, to arrange them in series. Thus he can arrange a graded series running from white through light and dark gray to black; and, though with more uncertainty, he can arrange the whole collection of colors in a series ranging from light to dark. This arrangement may be called the light-dark series, or the brightness series. Besides this, the observer notes differences of color, and if he start with a pure yellow and a greenish yellow, he can easily continue the series to green and blue and violet and purple and red and orange, back to yellow

again. This circular series is truly a remarkable phenomenon, the like of which does not occur elsewhere in the field of sensation, though it has some analogy to the octave in musical tones. Once the color circle is constructed, it is possible to make each color in it one of a brightness series, containing the shades and tints of one color only. Thus a large share of colored objects can be reduced to an orderly arrangement in two dimensions.

But the color circle will not include all our variegated objects; there is no place in it for pure white, black or gray. In passing from yellow around to yellow again, one nowhere finds a place that seems appropriate for gray, or for white, or for black. The best one can do is to consider black as the limit of the dark shades of some color, or rather of any color whatever, and white as the limit of the light or pale tints of any color; but still there is no place for the grays. A more deliberate survey of the collection of colored objects might however enable the observer to find a place for any given gray by taking it as the limit of a series of gradations of any color, gradations which, while preserving the same color tone and the same brightness, differ in the strength of the color, grading down from the strongest or fullest color obtainable at a given brightness, through duller and duller shades of the same color tone and brightness, towards the neutral gray. This is the saturation series, and its limits are on the one hand the most saturated color of a given brightness, and on the other hand a gray of the same brightness. The same gray would stand as the limit of a saturation series for any color tone, and different shades of gray might stand as the limits of different saturation series of the same color, but of different brightnesses. Though less obvious to the observer than the brightness or the color series, these saturation series can be detected by reference to sensations alone, without knowledge of the physics of the matter. But whereas there is essentially but one brightness series and but one color series, there is an indefinite number of similar saturation series, according to the brightness of the gray chosen as the limit, and according to the tone of the saturated color chosen as the other limit.

Since sensations of light and color can be arranged in these three ways, according to color tone, according to brightness, and according to saturation, it is natural to attempt a synthesis of all

three arrangements into some composite scheme. No two-dimensional scheme will accomplish this synthesis, but it is is possible to do it in three dimensions. If all the color tones which agree in brightness and in saturation are first arranged around the circumference of a circle, a gray of the same brightness may be located at the center of the circle, and along each radius may be arranged the saturation series of a given color, grading from neutral gray to the greatest saturation occurring at the given brightness. Thus the plane of the circle will contain all the colors, including gray, which have the same brightness. Similarly, in another plane, one might construct another color circle of another brightness, with its corresponding gray and saturation series; and, by proceeding in this way, and piling the planes in the order of brightness, with the corresponding color tones always in corresponding positions on the various circles, one should finally include all possible sensations of light and color in a single three-dimensional scheme, which may take the form of a cylinder, bright on top and dark beneath, gray at the center and saturated on the outside, red along one element of the convex surface and blue along another. Practically, to be sure, there is some difficulty in assigning to each color its exact position in this cylindrical diagram, since, though grays and the shades of any one color can be arranged with considerable assurance in the order of brightness, and though colors of the same tone and of the same brightness can be readily arranged in the order of their saturation, it is subjectively difficult to make sure of equality of brightness or of saturation between colors of differing tone. Theoretically, however, every sensation of light and color would find a fixed place in the cylindrical scheme.

It is customary to refine a little on the cylinder in such a way as to do justice to certain minor facts regarding the relations of the sensations to each other. Thus, while the colors of any given brightness and saturation can be arranged in a color circle, the circle will not contain so many distinguishable steps, or barely noticeable differences of color tone, when the brightness is very low or very high, or when the saturation is low, as when the brightness is medium and the saturation as great as possible. As far as concerns saturation, this fact is already done justice to in that the less saturated colors are placed always towards

the center of their circle, and therefore lie in a smaller space, or shorter circumference, than the more saturated colors of the same brightness. To do similar justice to the fact that the color circles for bright and dark colors contain fewer distinguishable colors than for medium brightness, the cylinder is made to taper both above and below into a double cone. No red or blue can be found as bright as the brightest white, and therefore white stands alone at the upper apex, which perhaps should be continued upwards into a line of whites, of increasing brightness and all brighter than the brightest color. No color is as dark as the deepest black, and therefore black stands alone at the lower apex, and possibly this also should be prolonged into a line.

A still further refinement is sometimes introduced. To some observers, the color circle is an imperfect diagram, because it seems to indicate a perfectly gradual and uniform change of color tone throughout the series. They seem to notice certain turning-points at which the series alters in character or direction. From red through orange to yellow, the series appears to them homogeneous throughout, and is properly represented by a straight line; but as soon as yellow is passed, and a tinge of green appears, the series has taken a turn and started off in a new direction, namely, towards green. To some observers it seems proper to discard the circle for a square, with four somewhat rounded corners at red, yellow, green and blue. Others are unable to detect any turning-point in the red or green, but only in the yellow and blue; while others still are unconvinced of any such turning-points at all. Different observers differ also in the exact location of the turning-points, and it may reasonably be doubted whether, with a sufficiently great number of colors at hand, graded by equal fineness throughout the series, any turning-points would appear to exist. At any rate, whether the square be substituted for the circle, and the double pyramid for the double cone, or not, is a question of minor importance, since all the main facts are equally well schematized by either diagram.

The fact should not be overlooked that these diagrams are not intended to indicate anything regarding the stimuli arousing the sensations. What is indicated is simply the possibility of arranging colors in series according to brightness, saturation and color tone, with no regard to the physical or physiological pro-

cesses which arouse these sensations. The color pyramid is a purely psychological affair. If psychology were kept absolutely pure, that is limited to the study of sensations and other states of consciousness and isolated from their physical conditions and effects, then the present paper should be concluded at this point with the addition of some comment on the aesthetic value of the different colors: apart from this all the perfectly pure psychology of light is summed up in the color pyramid; everything else involves some knowledge of the stimulus which gives rise to the sensation and of the relation of stimulus to sensation. Few psychologists, however, care to remain so pure as this; most of them wish to advance to a knowledge of conditions, effects and other relations. But, at any rate, the system of facts symbolized by the color cone or pyramid is an important part of the science of light.

Starting out from the three-dimensional system of sensations of light, one naturally inquires next as to the corresponding dimensions of the physical stimulus. But soon one is convinced that there are no dimensions of the stimulus corresponding precisely to the scales of color tone, brighness and saturation. In a rough and general way, one finds that the scale of color corresponds to the scale of wave-length, the scale of brightness to the scale of intensity or energy of the stimulus, and the scale of saturation to the degree of purity of a single wave-length as contrasted with the admixture of other wave-lengths. Thus, light having a wave-length of 700 millionths of a millimeter and thereabouts gives the sensation of red, light of 589 millionths gives the sodium yellow, etc.; light of small physical energy gives a dark color while light of great intensity gives a bright color; light that is homogeneous or monochromatic or, in other words, all of one wave-length, gives a saturated impression while light compounded of rays of various length gives an unsaturated color or even a neutral gray or white.

But these correspondences are far from perfect. In the case of saturation, if one start with light of one wave-length, and add to it, or blend with it, more and more white, *i.e.*, mixed light, the saturation will be decreased. But not all homogeneous light gives a saturated sensation; as, for example, the pure sodium

light produces an impression of paleness as compared with a good full red or blue. Saturation, therefore, depends on the wave-length, as well as on mixture. Besides, there is the curious case of purple, which may, certainly, appear saturated enough, though it can not be produced by the action of any one wave-length, but only by a mixture of long and short waves. Still further, saturation, as well as color tone and brightness, depends on the duration of the stimulus, and on the character of the light which has just previously excited the eye. A light which appears highly saturated at first sight grows paler and paler with prolonged inspection; and the most saturated effects can only be obtained by first looking steadily at a bright color, and then turning quickly to a somewhat darker shade of the complementary color.

The case of color tone is even more intricate. In a general way, it depends on the wave-length, but there are many important exceptions to the rule. Just as prolonged fixation of a colored light changes its apparent saturation, it may also change its apparent color. A light which appears orange or greenish yellow at first tends on prolonged fixation to change towards pure yellow, at the same time losing in saturation; and, similarly, a greenish blue or a violet changes towards blue. Yellow and blue themselves do not change except in saturation. There are a particular bluish green and a particular purplish red which, also, do not change in color, but only lose rapidly in saturation, verging towards neutral gray. This red and this green are boundaries, as it were, between the spheres of influence of yellow and blue. On the color circle they may be taken as extremities of a diameter, separating a yellow from a blue semicircle. To the fresh eye, the yellow half appears graded in color from purplish red through red, orange and yellow to green. The blue half appears graded from bluish green through blue, violet and purple. But when the eye has become sufficiently fatigued or adapted by prolonged exposure of the same parts of the retina to the same lights, then the yellow half of the circle appears yellow throughout, and the blue half blue throughout, though varying in saturation.

Color tone depends on the intensity of the physical light, as well as on its wave-length. If the intensity is sufficiently dimin-

ished, then, though the eye be allowed time to become well adapted to the dark, the distinction of color drops out, and only grays are left. Also, it is said, if the intensity of monochromatic light is sufficiently increased, not only do all the colors lose in saturation, but all except blue and yellow tend to shift towards one of these two colors, much as in prolonged fixation. Here again there are boundary colors between the yellow and the blue halves, and the boundary colors do not shift in color with increasing intensity, but only lose saturation and pass into white.

Color is also dependent on the size or area of the stimulus, since a minute area of color is likely to appear colorless, though a larger area of the same character would show its color.

There is still another exception to the rule of correspondence between color tone and wave-length, and it is a very curious exception, that is, color mixture. The sodium yellow, for example, can not only be produced by light of 589 wave-length, but also by the combined action of 650 and 550 in proper proportions, or by many other pairs of rays, one of greater and one of less wave-length than 589, provided only that neither of them differs too much from 589. In general, the same color tone as is produced by light of any given wave-length can also be produced by a mixture of other wave-lengths, one greater and one less than that whose color is to be duplicated. The mixed light does not betray its composition, but gives just as unitary a sensation as homogeneous light. The sensation gives no indication whether the light is homogeneous or mixed, except that, in general, homogeneous light gives a more saturated effect: and the greater the difference in wave-length between the two lights mixed, the less in general is the saturation of the resulting color sensation. But even this rule in regard to saturation has exceptions: so that, in short, it is impossible, from the color effect produced by a light, to infer anything with certainty and precision as to the wave-length or wave-lengths of the light. Reference should also be made again to the purples, which though fully as definite color sensations as any others, have no corresponding single wave-lengths. To the physicist, purple may almost be called a sham and illusion; it has no place in the spectrum, and does not represent any homogeneous ray as the

other colors do. Therefore it can not be allowed, in physics, a standing equal to that of the other colors. Nevertheless, as a sensation, purple has exactly as good a standing as any other color. It can not be regarded by the psychologist as a mere mixture of other sensations, for it appears to the observer quite as single and homogeneous as the other colors. It occupies its place in the color circle with the same dignity and assurance as any other color. In every respect it is on a par, psychologically, with other colors.

The grays and whites have somewhat the same curious position as the purples, since these sensations are not aroused by light of any single wave-length (unless, indeed, it be of very high or of very low intensity), but only by a mixture of different rays. Many different mixtures give the same effect—either a combination of all the rays in the proportion in which they are present in sunlight, or a combination of the two wave-lengths 656 and 492, or 585 and 485, or of 564 and 462, etc.; and also a combination of three, four or more rays properly chosen and adjusted. When two rays combine to produce the sensation of white, they are called complementary, and it is customary also to call the colors corresponding to the wave-lengths complementary colors. Strictly speaking, it is not the color sensations which are complementary, but only the rays of light; for there is nothing in the aspect of blue to indicate that, when combined with yellow, it would give gray; and nothing, indeed, is more surprising than to see for the first time a mixture of blue and yellow, on the color wheel, give rise to the neutral gray, from which all traces of the constituent colors have disappeared. Strictly speaking, again, yellow and blue, as sensations, are not constituents of gray. They have not been blended into the sensation of gray, but have simply disappeared, making way for the sensation of gray.

Color mixture, in general, is not mixture of color sensations, but mixture of stimuli.

Mixed stimuli give homogeneous color sensations. The same statement could not be made of any other sense than vision. One does not experience a salty taste, for example, by taking into the mouth a mixture of sweet and acid substances; nor

is the note *re* heard when *do* and *mi* are sounded together. There is something peculiar about the sense of sight in this respect.

There is still one other grand exception to the rule of correspondence between color tone and wave-length. This correspondence holds, at best, only for the ordinary polychromatic vision, of which the color circle is a symbol. Already mentioned is one instance of achromatic vision, namely, the case of very faint illumination. On passing from bright to dim light, one at first sees very little, but soon becomes adapted to the dark so as to see objects and distinguish the lighter from the darker. But in thus becoming adapted to dim light, the eye does not become adapted to differences of wave-length in the dim light, but all dim light is gray. There are two other instances of achromatic vision. First, there are the totally color-blind individuals, who recognize no distinction of light according to the wave-length. All wave-lengths are alike to them, aside from differences in brightness. The other instance is found in indirect vision with a normal eye. At the very outside of the field of view, lights can not be distinguished in color, but only in brightness, or, at least, only very intense lights can be distinguished in color, all others appearing gray. Another form of vision besides polychromatic vision with its three dimensions, color, brightness and saturation, must therefore be recognized—a form in which the color dimension is suppressed, and with it the saturation dimension, leaving only the dimension of brightness. Instead of a double cone or pyramid, therefore, this achromatic or one-dimensional vision can be symbolized by a straight line. According to the "duplex theory" of vision which seeks to justify these facts, this one-dimensional or mere brightness vision is a function of the rods of the retina, while the polychromatic or three-dimensional vision is a function of the more highly developed cones. This theory finds support in the fact that the achromatic periphery of the retina is almost free from cones, and in the strong indications that totally color-blind individuals are deprived of the function of the cones. The rods are believed to be more sensitive to very faint light than the cones, or, at least, to be capable of much better adaptation to very faint light. Therefore, in very

dim light, seeing only with the rods, one has only brightness and no color vision.

If polychrome vision is three-dimensional, and achromatic vision one-dimensional, one must also recognize the existence of a two-dimensional form known as dichromatic. Two imperfect instances of this form of vision have already been mentioned—that which results from great intensity of the light, and that which results from its prolonged action on the same portions of the retina. In both cases the color circle tends to be reduced to blue and yellow with gray at the boundaries between them. Therefore there is no further need of the circle, since a straight line with blue at one end, yellow at the other, and gray in the middle, provides a place for all the colors experienced in this dichromatic vision. Neither the color dimension nor the saturation dimension is wholly suppressed, but the two coalesce.

More important instances of the dichromatic system are found in indirect vision and in the common type of color-blindness. The outermost part of the retina gives, as has been said, achromatic vision, while the central area gives the complete system of colors. There is, however, an intermediate zone of dichromatism. The limits of this zone, to be sure, are not absolutely fixed, but vary with the intensity of the stimulus. It can be said in a general way that all colors appear, in the intermediate zone, as yellow, blue, or else gray. Scarlet, orange and olive green appear yellow; greenish blue and all the other blues, with violet and purple, appear blue. A certain green, or bluish green, appears neither yellow nor blue but simply gray; and the same is true of a certain purplish red. These are indeed the same boundary colors that were discovered in the previous instances of dichromatic vision. The color circle reduces to two radii, one for yellow in its different saturations, and one for blue, both meeting in neutral gray. The two radii may properly be considered as one diameter, and thus the color circle can be reduced to a straight line, perpendicular to that other straight line which symbolizes the variations of brightness. The double cone or pyramid is reduced to a double triangle.

The most common form of color blindness, best called red-green blindness, is also a dichromatism apparently identical with

that of the intermediate zone of the retina. Colors in the yellow half of the color circle are confused with each other to any extent, provided only brightness and saturation are suitably adjusted; and so also all colors in the blue half of the circle may be confused with each other. The boundary colors, often mentioned, are to the color-blind eye indistinguishable from neutral gray. In general, one can not institute a direct comparison between the sensations of the color-blind and of the normal individual; but a few valuable instances are on record of individuals color-blind in only one eye, and their testimony indicates that the colors which remain to the color-blind eye are, actually, yellow and blue, the same as in the intermediate zone of the retina; so that the color-blind possess a two-dimensional instead of a three-dimensional system of sensations of light.

The correspondence between color tone and wave-length, which is entirely lacking in achromatic vision, is partially present in dichromatism, since rays of greater wave-length give one color tone, probably yellow, and rays of short wave-length another color tone, blue. That is to say, any wave-length of over about 500 millionths of a millimeter gives always the same color tone, yellow, though in varying brightness and saturation; and any wave-length less than about 500 gives always the one color tone, blue, in varying saturation and brightness; while rays of about 500 give gray.

Enough has been said to make it clear that the relation between color tone and wave-length is nothing universal, uniform and necessary. The relation is in reality extraordinarily complicated; and to give some rational interpretation of this complexity is the province of physiology with its color theories. Between the physical light and the system of color sensations intervenes the eye, and especially the retina, a receiving and transforming organ, and something in its manner of transformation must, probably, be the cause of the intricate relations between the physical stimulus on the one side and the color sensation on the other. Without attempting to discuss the merits of the several rival theories of color vision, no one of which, probably, is fully adequate, the theory which commands most adherence from psychologists at the present day may be considered; that is, the theory put forward by Hering. No attempt is made here to follow Hering in

all details, nor to keep his ideas distinct from those of other contributors to the theory.

In the first place, the mechanism by which the retina transforms light into nervous impulses is, in all probability, either chemical or electrical or, most likely, electrochemical. The photic stimulus, impinging on the rods and cones of the retina, must arouse in them some movement of molecules or atoms, some migration of ions, some rotation of electrons; and this movement must in turn start the somewhat similar movement in the nerves which is propogated to the brain. Apparently there must be present in the retina some substances sensitive to light, such that minute motions are generated in them by the ethereal vibrations. Whatever the exact nature of this electrochemical motion may be, it must apparently be conceived as reversible. The electrons must be capable of rotating in two opposite directions, or the ions of migrating to and fro between two compounds, or the molecules of disintegration and redintegration similar to what is observed in the action of certain enzymes. The need for some such assumption is partly to account for the recovery of the retina after activity, partly to account for the positive character of the sensation of black, and partly to explain the opposition between certain rays and certain other rays in their action on vision.

Black is not, psychologically, a mere absence or negation, but is as positive as any other visual sensation. A mere absence of visual sensation is not black, but—simply nothing at all, as for example, the impression derived from a ray which falls on the blind spot or outside of the limits of the field of view. Moreover, black, or at least dark, is as essential as light for the uses of vision. All in all, it seems reasonable to conceive of the process set up by light in the retina as reversible, and such that after light, an absence of light will act, as a stimulus to the opposite motion to that generated by the light. Such a conception is by no means absurd, since it is possible to produce a photographic film which shall be insensitive, *i.e.*, remain in equilibrium, under light of a certain intensity, while it undergoes a change when the light is either raised or lowered in intensity from this level. For example, metallic silver in a solution of copper bromide tends to take the bromine from the copper and

make silver bromide. On the other hand, the action of light is to drive the bromine off from the silver and leave this in the metallic state. With a certain intensity of light, equilibrium is established between the tendency of the bromine to move to and away from the silver; but if now the light is increased, the equilibrium is disturbed and more bromine leaves the silver, whereas if the light is diminished, the equilibrium is again disturbed and more bromine passes from the copper to the silver. Electric currents are liberated by each of these opposed movements of the bromine ions.[1]

Something like this represents the minimum requirement for a light receiving organ—some substance or mixture of substances in which light sets up motion in one direction, while the inner tendencies of the mixture give rise to a movement in the opposite direction on the cessation of the light. Biologically, it seems reasonable to suppose that the retina has undergone an evolution such that, in its most primitive state, it provided for only one pair of opposed motions. Its photochemical substance must have been similarly though not equally sensitive to light of quite a range of wave-length, corresponding somewhat to the limits of the visible spectrum. This would then be a one-dimensional sense, providing sensations of light and dark in several degrees. The rod sense seems to remain still at this stage of evolution. It seems to have only one reaction to light, irrespective of the wave-length, and one opposed reaction to the cessation of light. The outer zone of the retina, mostly unprovided as it is with cones, remains essentially in this stage of evolution.

The intermediate zone of the retina apparently represents a second stage in the evolution of the visual sense; and the same may reasonably be conjectured regarding red-green blind individuals, since their eyes show no signs of any pathological condition. Color-blindness is not a disease, but is an innate condition, and may represent something like arrested development or a remaining of the retina at the same earlier stage of evolution as is found always in the intermediate zone. The characteristic of this dichromatic vision is that, in addition to being

[1] See Liesegang, "Schwarz als Empfindung," Zeitschr. f. Sinnesphysiologie, 1910, 45, 69-70.

sensitive to light and dark, it is also differentially sensitive to light of long and of short wave-length. It reacts to long waves by giving rise to the sensation of yellow, and to short rays by giving rise to the sensation of blue. It is probable that the retina, in this stage of development, contains, in addition to the substance which gives opposite motions to light and dark, some other substance or mixture or condition in which a motion in one direction is generated by the long waves and the opposed motion by the short waves. Photochemistry can afford analogies for such a condition. The motion generated by the long waves is not generated with equal ease by all of them, but most readily, it is probable, by waves having a length of about 570, and less and less by waves differing more and more from this length on either side. In other words, the photochemical substance in question is attuned to waves of one length, but responds also to waves not differing too much from this optimum. Similarly, the opposite motion in this substance is best generated by light of about 470, but in a less degree by other waves shorter than about 500. Accordingly, if one excites a dichromatic eye by light from different regions of the spectrum, beginning with the red end, he shall obtain, first, a very dull yellow, then more and more yellow till the maximum is passed, then less and less yellow till the neutral point at about 500 is reached, then a faint blue increasing to a maximum and decreasing again towards the violet end.

But along with this yellow-blue sense, dichromatic vision possesses also the light-dark sense, which responds to all rays within the visible spectrum by a sensation of light, having also a maximum not far from the maximum of the yellow effect, and shading off towards both ends of the spectrum. The total effect on the dichromatic eye from stimulation with any wave-length will therefore be a compound of the light-dark effect with the yellow-blue effect. At the neutral or boundary point of the yellow-blue reaction, the yellow-blue process being in equilibrium, only the light effect results. Again if yellow and blue rays act together, they neutralize each other so far as concerns the yellow-blue process, and leave only the effect of light of a certain brightness. Or, if any combination of long and short waves is so proportioned that the yellow tendency balances the blue tendency, only

the light effect remains. If the long waves overbalance the short in any mixture, the effect is yellowish; if the short waves preponderate, the effect is bluish. The saturation of any yellow or blue depends on the relation between the light-dark and the yellow or blue effects, and is greater in proportion as the light is homogeneous and in proportion as it is concentrated about one of the two wave-lengths to which the yellow and blue processes are most responsive. Saturation is therefore, from the point of view of retinal action, an incidental affair, and not worthy to be regarded as a dimension or independent variable. Yet dichromatic vision is, physiologically as well as psychologically, two-dimensional, the two independent variables being the light-dark process and the yellow-blue process.

Dichromatic vision is simpler and better understood than normal or polychromatic vision. It is natural to suppose that the latter is equal to the former *plus* some additional process, *i.e.*, that, in the course of evolution, some new photochemical substance or mixture has arisen which is differently sensitized from either the light-dark substance or the yellow-blue substance. Theories differ widely as to the nature of the addition which must be made to dichromatic vision to produce polychromatic vision—or in other words, as to the nature of the subtraction which must be made from the normal eye to reduce it to the color blind condition. The following consideration, however, seems to be important in this connection. Since yellow and blue lights are complementary both to the normal and to the color blind eye, and since, in general, the same pairs of wave-lengths are complementary to both sorts of eyes, it follows that what is added to dichromatic to make polychromatic vision must itself partake of the nature of a complementary, or must consist of two opposed processes of the same general nature as the yellow-blue pair. Otherwise, two colors which are complementary to the color-blind eye would not be so to the normal eye. Or, to put it otherwise, no single color added to a complementary pair like yellow and blue would give rise to the color circle, but only to half of the colors in it; and no single color added to yellow and blue would give white, since yellow and blue by themselves combine to give white, and the third color would be left over and give its tinge to the mixture. What is added must be of such a character

that the yellow-blue mixture *plus* the new addition shall give the same effect as the yellow-blue mixture alone,—namely white light—since all the colors mixed together give white. It is probable, accordingly, that the new development which gives rise to polychromatic vision is polarized as the light-dark and yellow-blue processes are polarized. In other words, one should surmise that some new photochemical substance has arisen in the central region of the fully developed retina—some substance admitting of two opposite motions, and so attuned as to give one of these motions under the action of a certain wave-length, and the opposite motion under the operation of some other wave-length; and the colors corresponding to these wave-lengths should be complementary. The problem would then be to ascertain the wave-length to which each of these opposed reactions is most closely attuned. There are indications, but not conclusive ones, that one of these wave-lengths lies in the neighborhood of 500, namely, in the green or bluish green. But, if so, no one wave-length can be assigned as the optimum for the opposed or complementary reaction, since the green has no complementary within the spectrum. The purplish red, complementary to the green, lies in the non-spectral portion of the color circle, and is produced only by the combination of long and short wave-lengths. It would seem, accordingly, that the red process is best attuned to no one single wave-length, but to a certain mixture of long and short waves. This is a condition of affairs that tempts one to speculation, especially in view of the fact that the longest waves in the visible spectrum are nearly, but not quite twice the length of the shortest. The visible spectrum has, in fact, often been likened to a slightly incomplete octave. One is thus reminded of the overtones in sound, and is led to suspect that a photochemical substance attuned to waves at one end of the spectrum would also be sensitive to waves of nearly twice the vibration rate at the other end. It might thus be really the fact that, under the conditions of absorption obtaining in the media of the eyeball, etc., no one ray of light would so effectively excite the red process as a mixture of long and short waves. Besides, to obtain the real effect in its purity, one would need to choose a stimulus which should give a balanced effect on the yellow-blue substance, as otherwise the red would be tinged with a proportion

of yellow or of blue. Now as the yellow process is excited by all rays up to the red end, and the blue process by all rays down to the violet end, the pure red effect could be got neither from the long waves nor from the short waves alone, but only by neutralizing the yellow effect of the long rays by the blue effect of the short. However, as these considerations are both complicated and speculative, it is wise to admit that the probable physiology of polychromatic vision is still undecided. Enough has certainly been said to justify the thesis that the correspondence between color tone and wave-length is far from presenting that simple character which would be suggested by the rudimentary statement that color depends on the wave-length.

The similar statement that brightness depends on the energy of the physical stimulus is also true only with very serious qualifications. To mention first one or two minor points, brightness depends on the spatial extent of the stimulus and on its duration. Either extent or duration can to a certain degree take the place of intensity of light. A very small surface intensely illuminated may appear less bright than a larger surface under somewhat weaker illumination. A weaker light acting on the eye for a twentieth of a second may appear brighter than a stronger light acting for a hundredth of a second. A light must act for a certain time in order to develop the full brightness to which it can give rise. This time for which it must act is called its "action time," and is, to be sure, very short, ranging from one-fifth of a second when the light is so weak as to be barely perceptible down to a thirtieth when the light is very intense.[1]

The apparent intensity of a light which acts for less than its action time is proportional to the time for which it acts; and this rule applies to intermittent light such as that reflected from a color wheel or such as that of an arc in an alternating current. Here one has, physically, light for a short time followed by darkness for a short time, the two alternating rapidly. If the light lasts for half of the total time, the apparent intensity is half of what it would be were the light physically continuous; and, in general, the apparent intensity of the light is the same fraction of its full possible brightness that the phase of light is of the

[1] McDougall, *British Journal of Psychology*, 1904, I, 151.

whole period. This relation between brightness and duration is familiar under the name of Talbot's law.

If, however, a bright light lasts for much longer than its action time, its apparent brightness begins slowly to diminish. The eye becomes adapted to it, and responds less strongly than at first. If a strong light is followed by a weak, the apparent brightness of the latter slowly increases and may finally come to appear much brighter than at first. Brightness depends almost as much on the condition of adaptation of the retina as on the intensity of the stimulus. On passing from bright to dim illumination, the adaptation of the eye proceeds rapidly for the first 1-2 minutes, and then more slowly for half an hour or even for several hours. The change in the sensitivity with adaptation is very great, as measured by the least intensity of illumination than can be perceived. The eye is at least several thousand times as sensitive after half an hour in dim light as after half an hour in the sunlight.

The apparent brightness of light is thus affected by the preceding stimulation. It is also affected by the simultaneous stimulation of other parts of the retina; or, in other words, the brightness of any one part of the field is a function not only of the intensity of illumination at that part but also of the illumination at other parts of the field. The main facts belonging here are known under the name of contrast; and contrast might well have been mentioned in discussing color, since the apparent color, as well as brightness, of any part of the field is liable to modification by the influence of other parts of the field. Contrast seems to be an example of the law of polarization or opposition that was spoken of under the head of color theories. If the brightness process is evoked in one part of the retina, this favors the darkness process in other, especially adjacent parts; and if the yellow process is evoked at one part, this favors the blue process at other parts. In general, the calling out of one reaction at one part favors the opposed reaction at other parts in proportion to their proximity. So, a bright light shining into the eyes causes a darkening of any other object which is being examined and interferes noticeably with clear and easy perception. Since contrast is strongest at the junction of the contrasting surfaces,

its effect is to accentuate the contours and outlines of objects, and it thus serves an important purpose in vision, since contours are of much value in recognizing objects. Contrast effects are generally overlooked, though all the time they are being utilized for purposes of sharp definition of objects. It is possible to measure contrast effects by comparing the apparent brightness of a surface subjected to the influence of some adjacent brighter or darker surface with the brightness of a control surface free from any strong contrast influence. The illumination of the control surface is varied till it appears equal to that of the surface affected by contrast, and it is found possible to express the degree of the contrast effect as equivalent to such and such a change in the objective illumination. As thus measured, the brightness contrast is equivalent to a constant fraction of the difference in illumination of the contrasting surfaces. This fraction is constant, in the sense of being independent of the absolute illumination and of the difference of illumination of the contrasting surfaces. It varies with many other conditions, such as proximity. But contrast is, by exception, relatively strong between two surfaces which differ but slightly in illumination; and it is here, especially, that the influence of contrast to accentuate contours is of importance. This fact has also been much used in photometry, in which the plan is always to bring the lights to be compared into immediate juxtaposition, without even a line between them, in order that contrast may accentuate any difference between them.

The apparent brightness of a light is thus dependent on a variety of conditions; and one of the most important of these has not yet been mentioned. Brightness depends very largely on the wave-length. This is obvious at once from the fact that the visible spectrum has limits much narrower than the full solar spectrum. The infra-red and ultra-violet rays produce no sensation of brightness, however great their physical energy. At the ends of the visible spectrum, the apparent brightness is low, though the energy of the rays may be considerable, especially at the red end. The brightest part of the spectrum seems ordinarily to lie in the yellow, and this is not simply because the yellow rays contain more energy than the rest, but because the

eye is most sensitive to rays of that wave-length. The brightness sense is attuned most closely to a wave-length of about 600 millionths of a millimeter, and less and less closely to rays differing more and more from that on either side. This is true of our ordinary or daylight or light-adapted vision. But in what is called twilight vision, which obtains when the eye is dark-adapted and subjected only to dim light, the brightness curve of a weak solar spectrum differs considerably from that of daylight vision. The maximum is displaced towards the green, and falls at about the wave-length 525; the red end is cut short, the longest waves no longer arousing a sensation, and the short waves have increased in their effect by comparison with the long. At the same time, as has already been mentioned, the spectrum loses its colors and appears simply shaded in gray. The darkening of the red in comparison with the blue is very striking and has long been known under the name of the Purkinje phenomenon. An object which appears of a bright saturated red in the daylight will become black in the twilight, while a blue which appears even less bright by day will still appear distinctly luminous in twilight vision.

The more exact study of the relative brightness of different parts of the spectrum, or in general of different colors, meets with the peculiar difficulties which are recognized by all who have undertaken heterochromic photometry. The pure brightness effect, which one desires to measure, is masked by the color effect. Such comparisons are not altogether impossible, for it is easy to select a brilliant orange which every one would agree to be brighter than a dull blue; or, again, a brilliant blue which every one would admit to be brighter than a dull orange. But when finer comparisons are attempted much uncertainty is felt, and some of the most experienced students of the matter have expressed themselves as very sceptical of the validity of such comparisons. Observers differ considerably in equating the brightness of different colors; and the same observer is likely to vary considerably from one determination to another, though he tends, with practice, to settle down to a rather fixed habit, which however need not be right.

On account of this difficulty in the direct comparison of differ-

ent colors, other methods of heterochromic photometry have been introduced. One is the method of indirect vision. Since the outermost zone of the retina affords no distinction of color, but only of brightness, different colors can be directly equated there, without need of discounting their color. But it is somewhat difficult and annoying to make fine comparisons in indirect vision. Another method is that of the flicker photometer, which has the advantage of giving uniform and rather precise results, although the results are not universally accepted as giving the comparative brightness of the colors. An intermittent stimulus should, apart from the inertia of the sense organ, always give rise to an intermittent sensation, no matter how rapid the rate of intermission. Since an intermittent light gives rise to a steady sensation at 25 to 50 intermissions per second, the eye must be admitted to have a considerable degree of inertia. After each new stimulus, the sensation does not cease abruptly, but dies away only gradually, and the next stimulus gives a new upward shove before the sensation has perceptibly declined from its first maximum; and therefore the sensation is continuous and steady. But if the stimulus is repeated at somewhat greater intervals, the decline from the first maximum before the upward shove of the second stimulus may be sufficient to be noticed; and then an unsteady or flickering sensation results. The greater the inertia of the receiving organ, the less will there be of flicker, and the more readily can it be abolished by increasing the rate of intermission. Again, the less the objective difference between the alternating stimuli, the less will be the flicker and the more quickly may it be abolished by increasing the rate of alteration. Now probably all admit the physiological distinction between the brightness and the color sense, even though the psychological effects of the two are so blended as to be hard to disentangle. If the inertia of the color sense should be greater than that of the brightness sense, then flicker due to difference in brightness would persist after flicker due to difference in color had been abolished. This seems to be the fact. For when two colors which differ as much as possible in color tone—namely, two complementary colors, are first equated as nearly as possible in brightness, the flicker between them disappears at a slow rate

of alternation in comparison with the rate necessary to abolish flicker between either of them and black.[1]

If the conclusion is justified that flicker due to difference in color is abolished at comparatively low speeds of alternation, then the flicker remaining at higher speeds is due to difference of brightness; and if this in turn is reduced to a minimum by adjusting the brightness of the colors, the inference would be that the colors had now been made equal in their effect on the brightness sense. If one is not disposed to follow this argument implicitly, one might yet agree that flicker would be reduced by anything which made the alternating stimuli more nearly alike; and if altering the intensity of one of the colored lights reduces the flicker to a minimum—since this change has not affected the color—it can hardly have acted otherwise than by equating the brightness effect of the two stimuli.

It appears possible, then, to make out a fairly good case, in theory, for the flicker photometer. But more reliance will probably be placed in a comparison of the results of this method with other methods of heterochromic photometry. A recently introduced method,[2] due to von Kries, and called the minimal field method, is based on the fact that very small spots of color, on a white field, may appear colorless, and, if properly adjusted in brightness, may become indistinguishable from the white background. It was found impracticable to bring the small spot of colored light into foveal vision, the color sense of that region being too acute. But a very few degrees of eccentricity sufficed to destroy the color sensation of the minute spot of colored light, and then its intensity could be adjusted till the spot disappeared. In this way, the relative brightness of different parts of the spectrum was determined, and the curve of brightness so obtained was compared with that obtained by the method of peripheral vision and with that obtained by the flicker method. The comparison (Fig. 1) shows very close agreement between the three methods. The maximum in all three is very close to the wave length of 600, and both slopes of the curve are as nearly coincident as could be expected in view of the errors of observation.

The results of all these methods differ in some important re-

[1] P. v.Liebermann, Zeitschrift f. Sinnesphysiologie, 1911, 45, 117-128.
[2] Siebeck, Zeitschrift f. Sinnesphysiologie, 1906, 41, 89.

spects from the results of direct comparison of different colors; and some authorities are indisposed to accept any results which are at variance with the immediate appearance. It seems wrong to them to assert that a given red is darker than a given blue, when the direct comparison would lead the observer to assert, often with complete assurance, that the red is the brighter. The question is, however, whether we intend, in heterochromic photometry, to study strictly the brightness sense. The brightness of

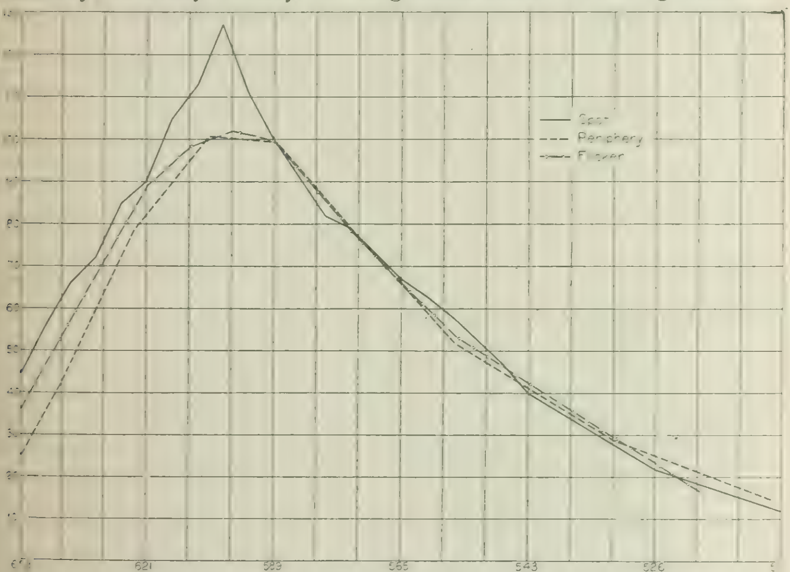

Fig. 1.—Relative brightness of different parts of the spectrum, according to three methods of heterochromic photometry.[1]

colors is so blended with their color effect that it is difficult—and there is no guarantee that it is possible—to separate the two by a mere effort of will and attention. Everyone admits that red is the most striking of the colors. It has an impressiveness which is not identical with brightness, but which can not be readily dissociated from brightness. It is probable enough therefore that what the observer is doing in photometry by direct comparison is to compare the total effect or impressiveness of two colored lights, rather than their brightness in the strict

[1] The curves obtained by the minimal field and indirect vision methods are taken from Sieheck, op. cit.; but the author has substituted, for the curve given by Sieheck to represent the results of the flicker method, a curve which is probably more reliable from F. L. Tufts, "Spectrophotometry of Normal and Color Blind Eyes," *Physical Review*, 1907, 25, 437.

sense. Whether this total impressiveness of a light is not what needs to be measured for many practical purposes is another problem to be worked out by still other methods.

No complete agreement can be expected between the results of different observers, by whatever method they attempt to compare the brightness of different colors. What is measured, in all photometry, is of course a subjective and not an objective phenomenon; it is the response of the eye and brain to light, and not the physical energy. There is no objective fact corresponding precisely to brightness or luminosity. The individual differences which appear are therefore not simply errors of observation, but indicate that the response to light differs in different eyes. This is especially the case in regard to the relative response to different rays. In that sub-class of the color-blind called red-blind or protanopic, there is very low sensitivity to the red end of the spectrum, so that a brightness equation between red and green would come out very differently with a red-blind observer than with the average observer. But it would be far from correct simply to set off red-blind individuals as a special class, and regard all others as alike. For even among individuals who have, according to all the tests, strictly normal color vision, there is a wide variation in the relative sensitivity to red and to green. Normal individuals vary in this respect at least in the ratio 2 to 1, and apparently, in exceptional cases, as much as 8 to 1. That is to say that one normal eye has been found to be as much as eight times as sensitive to red as another, in comparison with the sensitivity to green. This comparison was made by the flicker method, other methods also showing somewhat similar differences.[1]

Individual differences constitute a subject of much psychological interest, and perhaps the psychologist is more alive to the fact of such differences than the physicist or students of other sciences. Whatever function the psychologist tests, he has always found differences between individuals. These differences are in almost all instances to be regarded as differences in degree, and not as differences in kind. Differences in kind often result from the action of disease or injury; and differences which are practically differences in kind arise from special training, as, for ex-

[1] Catharina v. Maltzew, Uber individuelle Verschiedenheit der Helligkeitsverteilung im Spektrum. Zeitschr. f. Sinnesphysiologie, 1909, 43, 76-98.

ample, mankind can very easily be divided into those who can telegraph and those who can not, though there might be a few doubtful cases. Such sharp divisions of mankind in mental functions are seldom if ever found as the result of native differences. The case of color-blindness seems an exception to this rule, since each individual seems to be born with either dichromatic or polychromatic, or, very rarely, with achromatic vision. If mankind is really divisible here into three types or species as regards their color sense, the reason is that vision is really a compound of at least three senses, the brightness sense of the rods, and the yellow-blue and red-green senses of the cones. There is also, probably, a brightness sense of the cones, but a total color-blindness with integrity of the cone brightness sense is, so far as the author knows, not demonstrated. However this may be, it would seem that the line between the normal and the red-green blind individuals is not perfectly sharp; it seems to be bridged over, to a degree, by individuals classed as color weak, who may be regarded as possessing a red-green sense, but one of subnormal efficiency. Moreover, it is certain that individuals who are classed as strictly normal are yet not all alike in color sense. They show minor differences, some being less sensitive to red than others, some having the point of maximum brightness in the spectrum a little farther towards the green than others, some finding somewhat different pairs of rays complementary from others. All these differences can be readily understood in terms of color theory if it be supposed that the sensitivity of the several photochromatic substances differs slightly from one individual to another, and that the attunement of each substance to a specific wave-length is also capable of some degree of variation.

The most important bearing of the facts summarized in the color pyramid is in relation to theories of retinal action. Though the facts are strictly psychological, their interest is mostly physiological. Most of the psychological interest is in the utilization of light for purposes of perception. From the point of view of utility, or from the point of view of mental life in general, the important thing is not the mere occurrence of a sensation of such and such brightness, color and saturation, but the perception of objects and of their qualities and conditions. The perception of objects depends very largely on the ability to observe

differences within the field of view. The differences of color or brightness serve as indications of the outlines and molding of objects. One of the most elementary acts of perception is the noting of a difference of brightness; and the study of such perceptions has been one of the great concerns of the psychologist. How small a difference of brightness can be observed? The answer to this question is by no means simple. In the first place, much depends on the manner in which the lights to be compared are presented to the eye. If first one stimulus is presented, and then, after an interval of a second or two, another, the two must differ considerably in intensity in order that their difference may be perceptible. A smaller difference can be detected if both stimuli are presented simultaneously in different parts of the field of view. But the smallest difference can be perceived when the two stimuli are not only present together in the field, but when one immediately adjoins the other, without so much as a line of demarcation. Even under these conditions, however, it is impossible to give a simple expression of the power of discrimination. One can not state that a difference of a certain number of meter-candles is the minimum perceptible; for the least perceptible difference varies with the absolute intensity of the stimuli. A difference of a small fraction of a meter-candle can be observed when the two adjoining surfaces have each an illumination of less than a candle-meter, where a difference of a thousand meter-candles will pass unobserved when the surfaces are very brilliantly illuminated. So familiar is this fact that no one thinks of expressing the least noticeable difference in absolute units; instead, the usual expression is to the effect that the eye can distinguish a difference of brightness when one surface is one one-hundredth more intensely illuminated than the other. The fraction varies with the individual and his training, as well as with the conditions of the observation; sometimes it may be as small as 1/200; but often considerably larger than 1/100. In so far as any such constant fraction can properly be used as an expression of the power of discrimination, the famous law of Weber is substantiated. Weber's law states that the least noticeable difference, for any given sort and conditions of discrimination, is a constant fraction of the total stimulus. If Weber's law were unqualifiedly true, the task of the illuminating engineer

would be limited to the consideration of questions of the color of light, since intensity would be a matter of indifference for purposes of perception. For if one of two surfaces reflects 10 per cent. more light than another under one illumination, so it does under any other illumination; and the difference would, according to Weber's law, be equally perceptible under all illuminations. As a matter of fact, Weber's law does not hold good at very faint or very intense illumination; but in both cases a larger fractional difference between the stimuli is necessary in order to be perceived.

The most thorough test of Weber's law in intensity of light is afforded by the experiments of König and Brodhun,[1] who operated with a great range of intensities, obtaining results as shown in the following table.

König and Brodhun's arbitrary units	Meter-candles (approximate)	Least perceptible difference
0.5	0.9	1/3.9
1	1.8	1/5.7
2	3.6	1/8.3
5	8.9	1/14.4
10	17.8	1/21
20	35.6	1/27
50	89	1/33
100	178	1/40
200	356	1/45
500	890	1/51
1,000	1,780	1/57
2,000	3,560	1/59
5,000	8,900	1/61
10,000	17,800	1/60
20,000	35,600	1/57
50,000	89,000	1/47
100,000	178,000	1/34
200,000	356,000	1/26

The fractions in the last column of this table show the least noticeable difference in intensity in relation to the total illumination. According to Weber's law, this fraction should be independent of the absolute illumination. When the whole range of intensities is taken into account, this is seen to be far from the truth: the fraction is large at small intensities, decreases steadily with an increase of intensity, then remains almost un-

[1] Sitzungsber. d. Berl. Akad. d. Wiss., 1888 and 1889.

changed for a considerable range of medium illuminations, and finally increases again at very high intensities. In strictness, indeed, the fraction seems scarcely to remain constant at all, but rather to decrease at first rapidly and then slowly to a minimum, beyond which it at first slowly and then more rapidly increases again. If it be admitted that the important thing in perception is rather the noting of a relative than of an absolute difference—since it is the relative difference which remains objectively unchanged under variations of illumination, and which therefore gives valid information regarding objects themselves, rather than regarding the light which chances to fall upon them—then may one consider perception as equally good wherever the fraction is equally small; and where the fraction is at its minimum one may properly speak of perception as being at its maximum or optimum. Thus the denominator of the fraction may be used as a measure of the goodness of perception, and a picture of the goodness of perception as dependent on illumination may be obtained by simply plotting the curve of the denominator. The curve would be unwieldy to plot on account of the great range of intensities, but inspection of the table shows that it would rise with increasing illumination, at first rapidly and then slowly, remaining nearly level for a considerable range of medium intensities and then slowly sinking again. The nearly level portion is that where Weber's law is approximately true; and, from our present point of view, this law, with its limitations, seems simply a statement of the fact that there is an optimum illumination for observing differences, but that this optimum is in the midst of a nearly level part of the curve. The facts in the perception of sound, weight, etc., admit of a similar formulation.

As to the illumination which gives the optimum perception, the results of König and Brodhun would assign about 10,000 meter-candles as the summit of the curve, with approximate equality from below 2,000 to above 35,000 meter-candles. But this holds good only for the special conditions of these experiments, in which the illuminated field was small and was viewed through a small aperture. Since the optimum illumination would undoubtedly depend not only on the intensity of the light but

also on the total quantity entering the eye, it is probable that, under ordinary conditions of vision, the optimum would be reached at a lower illumination.

Another favorite study of the psychologist is the speed of reaction to various stimuli. It is a curious fact that, in spite of the high development and importance of the sense of vision, the reaction to light is slower than to sound or touch. There is some element of slowness in the simplest reaction to light. The quickest response by a hand movement to the reception of light, when nothing need be attended to except barely to move the hand as soon as the light is seen, is about 0.160 sec.: while the quickest reaction to sound is usually below 0.150 and may sink to 0.120 or even to 0.100. Individuals differ considerably in their absolute times of reaction, but agree in the relative slowness of the reaction to light. Explanation of this fact is not yet agreed upon, and several possibilities remain open. It may be that the photochemical process of retinal excitation is slower than the mechanical process that takes place in the ear or skin; or it may be that the nervous pathways leading in from the eye are less simple and direct than those from the ear and skin; or it may be that the nerves from the ear and skin have better central connections with the motor nerves.

The reaction time is inversely related to the intensity of the stimulus. Increasing the intensity of the light causes the reaction time to decrease, as the following results[1] show:

Intensity in arbitrary units	Reaction time seconds
100	0.191
56	0.194
25	0.197
16	0.202
10	0.208
7	0.210
3	0.215
2	0.220
0.8	0.226

The lowest of these intensities is that of light reflected from "black" paper, and is still distinctly above the threshold; and the reaction time might be expected to rise to about 0.300 sec. just

[1] Froeberg. "The Relation between the Magnitude of Stimulus and the Time of Reaction," New York, 1907.

above the threshold. The differences in the above-quoted reaction time are certainly small; and they are so masked by accidental variations that only a long series of trials, with well-trained reagents, could give results as regular as the above. Even slight differences of speed are however sometimes of moment; and the results with the simple reaction may probably be taken as indicating that any process depending on vision gets started more quickly when the light is at least moderately intense than when it is feeble.

Increasing the area of the light surface causes a quicker reaction, as well as increasing the illumination; and, within the limits of the "action time," increasing the duration of the light also quickens the reaction.

Probably less is to be learned from the study of the simple reaction than from the study of what is known as the discriminative reaction; for, as already intimated, the most used power of vision is the perception of differences. Suppose an oblong card, white at one end and black at the other, is exposed to the eye with the white end sometimes on the right and sometimes on the left; and suppose that the subject is instructed to move as quickly as possible the hand on the same side as the white. Since it is necessary to discriminate white from black before reacting, the time is longer than in the simple reaction; and the time grows longer still if, instead of white and black, some other pair of stimuli is used which differ less one from the other than white from black, even though the difference may still remain, to ordinary observation, "just as easy" to observe as the difference between white and black. The following list of discrimination times[1] shows the facts.

Stimuli to be discriminated	Time of reaction seconds
White and black	0.197
Red and green	0.203
Red and blue	0.212
Red and yellow	0.217
Red and orange	0.246
Red and orange mixed with 25 per cent. red	0.252
Red and orange mixed with 50 per cent. red	0.260
Red and orange mixed with 75 per cent. red	0.271

[1] Henmon, "The Time of Perception as a Measure of Differences in Sensations," New York, 1906.

Here again the differences in reaction time are small, but even small differences may have some practical significance where speed is an object, as it always is, for instance, where any performance must be continually repeated.

The esthetic or effective value of light is also a topic lying within the province of the psychologist. Goethe observed that a landscape viewed through a red glass produced a cheerful impression, but viewed through a blue glass a somber impression. There is undoubtedly some special value in the color red; for, though not all individuals select this as their preferred color, all will probably grant it to possess a more exciting or stimulating quality than other colors. Féré[1] experimented on this matter by placing a dynamometer in a person's hand, and instructing him to squeeze it as hard as possible, at the same time subjecting him to lights of varied description. As compared with ordinary illumination, bright light gave a moderate exaltation of the muscular contractions, and dim light produced a moderate depression. Colored lights had a more pronounced effect, all being found stimulating, but red the most so, and next orange, then green, then yellow, then blue. These results were indeed gained from specially suggestible individuals; and repetition of the experiment with strictly normal individuals often fails; but it may be that the effects are still present, but slight and therefore masked by other causes of variation.

Many such questions, regarding the effect of different lights on perception, reaction and emotional tone, are of practical as well as scientific interest; and it is likely that in the future the psychologist will look to the illuminating engineer for data on these problems, fully as much as the engineer will look to the psychologist.

DISCUSSION.

John B. Taylor:— I should like to ask Prof. Woodworth for a few remarks on color-blindness from a sex point of view. I understand that one man in every two dozen is pretty distinctly color-blind, whereas in the case of women the ratio does not run higher than one in two thousand. The laws of heredity are definite in regard to color blindness, although to me they are somewhat complicated.

[1] Sensation et mouvement, 2d. edition, Paris, 1900.

S. W. Ashe:—There is one question I should like to ask Dr. Woodworth: where he fails in the direct comparison method of comparing two lights, red against green, does the element of fatigue ever affect his conclusions. I understand the eye is fatigued more quickly by red, and similar colors, than by yellow. If one is making comparisons between two different colored illuminants, and the eye is fatigued more quickly by one than the other, that might explain partially why it is so difficult to make an accurate comparison between two colors on the direct reading photometer.

E. L. Elliott:—I think there was a point brought up in regard to the photometer, that leads to the conclusion that after all the practical side of it is—what can one see best by it? It seems to me that side of photometry, so far as illuminating engineering is concerned with it, has been very much overlooked. The object of light, so far as the illuminating engineer is concerned, is to see, and that illumination is best which enables one to see best the particular thing which he wants to see. Hence the so-called acuity vision photometers are in effect the only practical ones from the illuminating engineer's standpoint. The others are interesting from the standpoint of pure science. If one can read under a certain intensity of illumination of green light, and equally well under a certain other intensity of red light, then the values of these two lights for practical purposes are identical, whatever they may show on a flicker photometer or any other photometer.

D. Edgar Rice:—I wish to make a suggestion in respect to Mr. Elliott's statement—it is true that the most valuable use of photometry is the practical side of it—to discover what light is best adapted for practical purposes. The objection, as I see it, to the visual acuity photometers is that, while they do measure visual acuity, they do not measure intensity of light. Two different factors enter into the problem, namely, the ability to see under lights of different colors, and the comparative intensity of those lights. One may have a red light, or a green light, and determine under which illumination he can read the better, but he is not able to say which of these is the brighter light: it is the purpose of photometry to determine this question. One may compare

these lights with respect to their energy and determine which is the more efficient light, on the basis of the energy entering into each, but he must have some independent means of determining the relative brightness of these two lights before their visual acuity can be compared; and it is for this reason that the use of the photometer is absolutely necessary. A scheme which might be followed in a problem of this kind is to make the intensity comparison so that one can say that a certain red light is exactly as bright as a certain green light; and then when this equality has been established, each light should be used for reading to ascertain which of the two gives the greater efficiency.

I have done considerable work in visual acuity with different colored lights, and the results of my observations show that the red light is more efficient, so far as visual acuity is concerned, than the other colors. It is about equal in efficiency to illumination from the ordinary carbon filament lamp. With some observers it is higher, and with some lower. Of the three colors, red, green and blue, the red gives the highest efficiency, and the green is considerably better than the blue. I expect to do more work on this subject, to determine the matter with greater accuracy, but I think these results may be accepted as practically correct.

I think that the element of glare is one which enters into the problem of visual acuity. In lights in which there is a predominance of green and blue wave-lengths, there is more glare than there is in the red, and I think that is to a great extent the cause of the difference. If one looks at black characters on a white sheet illuminated by red light, the black stands out clearly, whereas if the same characters are observed with either green or blue illumination the same degree of distinctness will not be perceptible.

Dr. A. H. Elliott:—It seems to me that the psychological side of light is a most practical one, and one which can be applied in the every day problems of illumination to a far greater extent than one might perhaps at first realize. So is psychology related to esthetics. The conditions of feeling, tone and atmosphere may not be elements which appeal to the purely mechanically inclined designer of lighting installations, yet they have

more meaning and stand for much more in the application of light than saying that there is such an intensity of foot-candles or so many effective lumens per watt in that installation.

Prof. Woodworth:—A question has been asked regarding color-blindness in its relation to sex. I think it is true, as the speaker said, that about one in twenty to twenty-five males appears to be color-blind in the form which I call red-green blindness. Those who are afflicted with total color-blindness are extremely rare. I think perhaps from fifty to one hundred cases have been scientifically tested and proved within thirty years, although very likely more than that number have existed. The totally color-blind eye has an apparent lack of the cone sense, and a consequent ill adaptation to bright light and lack of sharp vision. Such an individual is often betrayed by the fact that he cannot hold his eyes steadily. The reason is that the person who lacks the cone sense has no foveal vision, and must look aside, and in doing that he goes against the physiological tendency of fixation. The subject of total color-blindness has been worked out in a very interesting manner from that point of view.

It it well known that the color-blind person cannot be safely allowed charge of an engine or boat, nor can he be recommended as a purchaser of dry goods, and he is precluded from many occupations. I know, a number of such individuals in thoroughly good health who have excellent use of the eyes for all practical purposes, perfectly normal, in all respects, aside from the fact that they are color-blind. They may not know it, and may simply think they have a little difficulty in distinguishing colors.

Color-blindness can be tested by rather simple means, and without much scientific study. In females it is true, a comparatively small fraction are supposed to be color-blind. There has been some doubt raised as to whether the results are quite correct, and whether females are not influenced by the greater keenness of the feminine mind in not being caught in making mistakes in the selection of colors. It is a matter of pride with them, and a social necessity among them. That may occasion, as it does with a color-blind man, some compensation for color-blindness by his extra careful attention to saturation and brightness of

yellow or blue effects. Many color-blind people, who realize their deficiency, train themselves to be unusually careful in the selection of colors. Prof. Hayes, of Mt. Holyoke College, for women, has been testing a considerable number of individuals, and he finds a larger proportion of them than is usually supposed to be color blind or color weak. There is no doubt that a somewhat lower fraction of women than men are color-blind. The whole thing is hereditary, and not subject to reduction by training. All color tests, which required a careful matching of colors, seems to show that the average woman is better in matching than the average man.

A question was asked regarding fatigue in photometry. As far as I understand that matter, the theory is this: The red and green processes are more readily fatigued than the yellow and blue. Fatigue is least with the white and black, with the yellow and blue following, and then come finally the red and green. If one looks at a colored light, it appears that the red light will produce an element of fatigue before the yellow light. If two lights, red and green, of equal brilliance, are compared, I do not think that there will be any difference in the result from the standpoint of fatigue. If one compares two that are unequally mixed, yellow and the other two, it might cause a change. But this would probably affect only the color, and not the brightness equation. The only experiments I know of relative to fatigue in photometric work are the negative results of Prof. Tufts, in comparing different parts of the spectrum, in one case with a fresh eye, and in another case with a fatigued eye; he got the same curve of brightness in both cases. I suppose, as far as I can gather, that one would be safe in photometric work in neglecting the question of color fatigue.

TRANSACTIONS OF THE

Illuminating Engineering Society

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COUNCIL NOTES.

The council held a meeting June 9th, in the general office, 29 West Thirty-ninth Street, New York. Those in attendance were James T. Maxwell, vice-president; A. S. McAllister, L. B. Marks, chairman of the finance committee; George Ross Green and Preston S. Millar, general secretary.

Monthly reports were accepted from the secretary and the chairman of the finance committee. In the secretary's report the total membership was given as 1,480 members, which figure did not include the applications on hand. The report of the finance committee constituted an approval of the May vouchers aggregating $391.72. Payment of these vouchers was authorized by the council.

From the committee on policy the following report was received and accepted:

The first meeting of the committee was held in the general office of the society on the afternoon of May 19, 1911. All the members of the committee—President A. E. Kennelly and Messrs. Louis Bell, W. H. Gartley, L. B. Marks, E. P. Hyde, V. R. Lansingh, C. H. Sharp, and P. S. Millar—were present.

The business which came before the committee consisted of the suggestions of the committee on section development, certain suggestions made by individual members of the society, and suggestions offered at the meeting by members of the committee. As a result of their deliberations the committee desires to make the following recommendations to the council:

More determined efforts should be made to obtain manuscripts of papers sufficiently in advance of section meetings to permit advance copies to be issued with a view to promoting oral and written discussion.

A committee on reciprocal relations with other societies should be appointed. This committee should investigate the feasibility of extending co-operative work and should consider ways and means. If practicable, other societies should be advised that, if at any time they de-

sire to devote a meeting to some subject in the field of illumination, the society is inclined to co-operate if desired. The work of this committee might comprehend plans for the holding of occasional meetings under the auspices of the society in cities where there are not sections of the society.

Sections of the society at large should, as opportunities arise, hold joint meetings with correlated societies. It is desirable to let it be known that the society is prepared to hold joint meetings, assuming its share both in the way of presentation and discussion of papers and of costs, with the understanding that desirable papers may appear in the Transactions of all organizations which join in the meeting.

It is desirable for each section to have a papers committee which should work in close touch with the committee on papers.

Some means of assuring closer co-operation of council and section boards is desirable. Great care should be exercised by the nominating committee in selecting vice-presidents with a view to securing for these important offices men who will be active both in the council and on the section boards.

To assure reasonable handling of section elections, the following scheme of election is recommended for adoption as a by-law.

Not later than April 1st of each year, the board of managers of a section shall appoint a nominating committee of five members of the society, of whom at least two shall be past officers of the section. This committee shall submit a list of nominations for section officers to the general secretary not later than May 1st. If the term of office of the vice-president representing the section shall expire at the end of the year, such list shall include the names of five members suggested for consideration for the office of vice-president. The list shall be submitted to the section membership with the notification of the June meeting. Election of officers shall be held at the June meeting of the section and shall be by ballot. At the same meeting three names from among the five suggested for the office of vice-president by the nominating committee shall be submitted to the board of nominations which meets in November.

A committee should be appointed to prepare for publication an elementary discussion of the principles of good illumination, including of course only such points as are established beyond peradventure and which the membership of the society can endorse. The widest practicable publicity should be given such discussion, both in the popular press and through the society's own publication.

A prospectus should be prepared for use in promoting the society's welfare.

The committee advises against certain proposals, as follows:

It is not desirable at this time to establish a class of resident members.

It is not desirable to make all members of the council ex-officio members of the board of managers of the nearest section.

It is not desirable to substitute the report of a committee for the stenographer's verbatim report of discussion at section meetings.

It is not desirable at this time to specify which of the section officers is the executive chiefly responsible for the conduct of the sections' affairs. For the present at least it is considered preferable to permit each section board to determine this in a manner best fitting its local conditions.

The committee discussed at length a proposal to recommend a change in conduct of sections or section organization. To remedy certain unsatisfactory features of the present situation and to assure more effectiveness, it was thought that quarterly meetings might be held in the cities where section headquarters are located or in other cities, each meeting to form a small convention and being of sufficient importance in both number and quality of papers to bring out an attendance from other cities. This plan might be more effective than the present plan of holding monthly meetings in four cities. It was concluded that the time is not ripe for final consideration of such a proposal and it is recommended that the matter be discussed at the meeting of all section officers which will probably be held at the time of the next annual convention.

A. E. Kennelly, Chairman,
Louis Bell,
W. H. Gartley,
E. P. Hyde,
V. R. Lansingh,
L. B. Marks,
C. H. Sharp,
P. S. Millar.

It was resolved that the foregoing report be approved by the council, submitted to the president for action, and printed in the TRANSACTIONS.

It was resolved that a vote of thanks be extended to the committee on policy for their prompt and comprehensive report.

A resolution was passed authorizing the president to appoint a committee to prepare a primer embodying the principles of good illumination.

A recommendation that the president be authorized to appoint delegates to attend the International Congress of Applied Electricity in Turin was received from the executive committee. A resolution to that effect was adopted.

A committee was appointed to revise the constitution and by-laws.

SECTION MEETINGS.

CHICAGO SECTION.

The concluding meeting of the season was held by the Chicago section at the Kuntz-Remmler Restaurant directly after luncheon on June 15th. The Chicago convention committee reported progress through its chairman, Mr. G. C. Keech. Extracts from the report of the committee on policy were read by Secretary Bernhard. The nominating committee reported through Mr. Keech the following list of nominees for section officers for the ensuing fiscal year: Chairman, R. F. Schuchard; secretary, A. L. Eustice; managers, Charles A. Luther and A. J. Morgan. These were elected by joint ballot.

Mr. W. D. Bradley then presented his paper on "Natural Daylight Illumination." This was discussed by Messrs. G. C. Keech, J. R. Cravath, F. A. Vaughn, C. A. Luther, T. H. Aldrich, F. J. Pearson, C. C. Schiller and W. D. Bradley.

NEW YORK SECTION.

The New York section held its last meeting of the season June 8th. Mr. S. W. Ashe read two papers, one "A Corporation Graduate Course in Illuminating Engineering" and the other "Notes on Comparison of Illuminants." The latter paper called forth considerable discussion. Both papers appear elsewhere in this issue of the TRANSACTIONS.

The following officers for the ensuing season were elected: Chairman, Bassett Jones, Jr.; managers, H. T. Owens and Mr. H. H. Seabrook. Mr. A. J. Marshall was reelected secretary.

NEW ENGLAND SECTION.

The New England section concluded its season at a meeting held June 12th. The meeting was devoted to a discussion of Mr. S. W. Ashe's paper "Notes on Comparison of Illuminants." which was read at the New York section meeting June 8th. As in the case of the latter-mentioned meeting, the paper elicited much discussion.

PHILADELPHIA SECTION.

At the last meeting of the current season held June 16th, the Philadelphia section elected the following officers for the next

season: chairman, J. D. Israel; secretary, L. B. Eichengreen; managers, C. W. Wardell and Prof. A. J. Rowland. Two papers; "Filament Ignition of Gas" and "The Lighting of a Garage by Electricity" were read by Mr. Howard Lyon and Mr. R. N. Zeek respectively. Both papers were discussed at length.

THE 1911 CONVENTION.

The fifth annual convention of the society will be held in Chicago September 25th, 26th and 27th. A definite program has not yet been arranged, but the plans under way augur well for an unusually successful convention. The attendance is expected to be not only a record one, but more indicative of the national aspects of the society than any of the previous conventions which were all held in the East. Among the papers to be presented there are several which will constitute notable contributions to the literature on illuminating engineering.

MILL LIGHTING.[1]

BY G. H. STICKNEY.

Mills embrace a wide range of manufacturing, largely where processes are continuously repeated. From the lighting standpoint, there is more difference between different kinds of mills than there is between mills and factories. For example, the lighting of textile, flour, steel and powder mills, are each radically different from the others, while a print works may resemble a textile mill in some of its processes, or an iron works or iron foundry may resemble a steel mill.

Owing to the difference in commercial conditions and requirements, the improvements in illumination obtainable with the recent developments in illuminants were first applied in store lighting. The value of improved illumination was not so evident to mill operators as it was where commercial competition of salesmanship created a demand for more light. In mills and other industrial establishments economy is apt to delay the adoption of new improvements requiring an initial expenditure. However, economy is the very demand which is to-day compelling the adoption of the new lighting units and improved methods for mill lighting.

PURPOSE OF LIGHTING.

The fundamental and primary purpose of mill lighting should be to insure safety to the employee. The second and usually the severer requirement is economy of production. All must clearly understand that the light in the mill is for the use of the employee, to enable him to see to perform his duties safely and expeditiously.

Last fall, the author had the privilege of attending a convention of iron and steel electrical engineers. The keynote of the entire discussion, which lasted for five days, was safety. The importance assigned to this subject would certainly surprise those who hold the popular opinion, that the steel manufacturers are careless with human life. Suitable illumination was rightly

[1] A paper read before a meeting of the Philadelphia section of the Illuminating Engineering Society, May 19, 1911.

credited as one of the principal factors in the prevention of accidents.

Mr. E. L. Elliott, published recently in the *Illuminating Engineer,* some curves prepared by Mr. John Calder, giving statistics of the number of fatal accidents occurring in some 80,000 shops and factories throughout a period of three years. These curves showed that the number of accidents in the darkest winter months was approximately 40 per cent. more than during the summer season. The conclusion drawn was that inadequate illumination was responsible for the increased number of accidents during the winter season. It is of course, evident that humanitarian considerations demand a good illumination. It is just as true, though not perhaps quite so thoroughly understood, that business considerations demand suitable illumination, not only in order to insure the safety of employees, but also to obtain the best economy of production.

VALUE OF GOOD ILLUMINATION.

With proper illumination it is possible to obtain a larger production, and a better grade of product, with a smaller loss of material through defects or breakage. The gain in any one of these three factors, will almost invariably more than outweigh the cost of reasonably good illumination.

While accurate data, as to the relation between cost of illumination and the cost of product output is not available, it is readily seen that the lighting cost is relatively small. Statements have been made and quoted by recognized engineers to the effect that the cost of good illumination is about one-half of one per cent. of the wages of the workmen benefitted by it. In connection with the lighting of a paper mill the superintendent made a rough estimate that the cost of the lighting—24 hours operation—was less than the value of the output for five minutes, or about one-third of one per cent. The gain in quantity of output alone does not have to be large to fully repay the lighting cost.

Certain steel manufacturers are now making a careful study of their lighting from the standpoint of economy, and are collecting considerable data as to the amount of light necessary for the proper performance of certain processes. Any investiga-

tion of this kind is bound to bring out the great gain which can be made in an average manufacturing plant by the provision of suitable illumination. It will also show that by the use of modern efficient illuminants, properly equipped and located, the gain can be made without a large increase in the cost of lighting and, in fact, often with a reduction in cost. In many cases such improvements are retarded by the fact that obsolete lighting equipment represents a relatively large investment of money. The expenditure necessary to modernize lighting in any mill is a relatively small item compared with the cost of the year's operation, and if capitalized according to the usual practice of figuring, depreciation and interest will prove a comparatively small item.

THE WORKMAN.

Attention has already been called to the fact, that the light is provided for the use of the workmen and should, therefore, be suited to their needs. One must not make the mistake, however, of trying to humor their whims. The average workman is not an illuminating engineer. Unfortunately, he often fails to realize it. It has been observed that when the workman is allowed to use his own ideas he is inclined to use bare glaring lights, so that they shine in his own eyes or those of his fellow-workmen. This results in the demand for an intensity several times greater than is really necessary, and instead of facilitating his work actually retards it and injures his eyes. An interesting case of this sort was reported some time ago by Mr. L. B. Marks, who found that the workmen in a particular factory were able to work satisfactorily with a daylight intensity of 8 foot-candles but insisted that they required 72 foot-candles under artificial lighting. By rearranging the lighting, he was able to provide evenly diffused illumination of reasonable intensity which was not only much better for the workmen but reduced the lighting cost.

It is very important, therefore, in redesigning the lighting of any industrial plant to study and determine the real needs and then install the lighting in such way as to bring it as little as possible to the attention of the workman, avoiding any suggestion that he can have it changed as desired.

In actually planning a mill lighting installation there are three principal factors to be considered, in order to secure the best possible result: first, process to be lighted; second, construction of the building; and, third, the illuminant available.

PROCESSES.

In many important processes the requirements are similar and the difference in lighting is principally one of degree. Certain other processes are special and require particular treatment. In order that the lighting may be suited to its purpose, it is necessary that the process should be understood so as to ascertain the way in which the workmen will use the illumination. For example, in the illumination of a lathe it is desirable that the strongest light should fall on the tool point. The simplest way of obtaining this result is to make sure that the nearest light source is in front of the lathe bed to the right and above the tool level. If this direction of light cannot be obtained advantageously with a general illumination, it will usually be necessary to supply a small portable lamp.

It is obviously impossible to fully discuss all mill processes fully in a single paper, but a few comments on some important operations may serve as useful suggestions.

PAPER MILLS.

In the lighting of a paper mill the processes of grinding and treating do not require a very high degree of illumination. The paper machine usually constitutes the principal lighting problem. The required intensity of illumination is not very high, but quite frequently the lighting is handicapped by the presence of steam and vapor. In some cases the machines are hooded, so that all the illumination must be received from the sides. It can readily be seen that any break or interference requires a stoppage of the entire machine, so that it is very important that the illumination be absolutely reliable and ample to permit quick and easy adjustments. In case of a break in the fabric it is necessary for the workman to see to thread the end through the machine quickly. Each minute of shutdown means a considerable loss of output. Most of the paper mill machinery has in the past been lighted by portable lamps. I believe better results

can be obtained by means of 40- or 60-watt tungsten lamps with directing reflectors permanently installed along the sides of the machine at a sufficient height to protect them from breakage.

TEXTILE MILLS.

Textile mills include cotton, woolen, silk and thread mills. As far as lighting is concerned this class might also include knitting mills, print works and all textile dye houses. The lighting requirements for cotton, linen, wool and silk, corresponds somewhat for similar processes, varying in degree, in that the darker and finer grades of goods require higher intensity and better illumination than the coarser and lighter colored grades. In all these textile mills the illumination requirement becomes more severe as the finishing process is approached. That is, the weaving and inspecting require better illumination than the breaking, carding or spinning. In lighting a weave room the size and arrangement of the looms should be considered in determining the size and location of lighting units. Especially with high looms care must be taken to locate lamps so as to avoid objectionable shadows. It is necessary for the operator to see the separate threads of the warp and detect breakage or other irregularities in the weave. The breakage of a single thread, if not immediately detected, may spoil a valuable piece of cloth. After weaving, the cloth is usually inspected on the tables or reels and a relatively high intensity of light is required, especially with black goods. In some cases daylight quality of light is necessary. In dye rooms a moderate illumination is all that is required, except for the inspector's office where a color matching light is required for the illumination of samples.

STEEL MILLS.

In steel mills the best result is generally obtained with general illumination. In hot rolling mills it is only necessary to provide a sufficient light to permit the employees to move around with safety. In this process the red hot billets furnish sufficient illumination for the working of the processes. In fact, more is demanded from the lighting equipment when there are no billets going through the mill. All processes where powerful machinery or overhead cranes are present require moderate illumination to insure safety.

DIFFUSION AND DIRECTION OF LIGHT.

Diffusion and direction of light are two important characteristics of good mill lighting. If the diffusion is good, the requirements for direction are less severe; and on the other hand with suitable direction of light it is possible to get along satisfactorily with less diffusion. A combination of glare and wrong direction of light is a common and serious fault. Diffusion is usually obtained by the use of translucent glassware, or diffusing reflectors. It is invariably accompanied by a loss of light, which is to a certain extent dependent upon the degree of diffusion obtained. Particularly where considerable dust and flyings are present accumulations of dirt on the glassware tend to reduce the glare and also to increase the loss of light. In such cases the use of clear glassware is not so objectionable as would appear at first thought. Frosted glass and rough surfaces tend to facilitate the accumulation of dirt and dust and, hence, should not be used in such places. Glare is almost always objectionable. I remember but one case having been called to my attention where glaring lights, as such, were desired. This occurred in a steel mill where the men working with red hot billets preferred a rather glaring light. The explanation for this choice was that the continual readjustment of the eyes, occasioned by looking away into the dark part of the mill, caused considerable eye strain.

DISTRIBUTION.

Another important feature of mill lighting is the distribution of light. The workman's attention is most readily directed to points where there is high illumination. Whether the lighting should be approximately uniform or concentrated in spots, depends upon the nature of the work. Usually there are places in mills which require more intense illumination than other parts. In some cases it is practicable to arrange the lighting so that the most important machinery receives the strongest light while the intensity grades off to the less important parts of the room. The danger, however, is that the spotted lighting will not vary according to the requirements. For example, in weaving, the warp requires approximately equal illumination for its full width. A bright spot of light in the middle of the warp may

interfere with proper observation of the ends, rendering the lower intensity less effective by contrast.

GENERAL ILLUMINATION VERSUS LOCALIZED ILLUMINATION.

A few years ago there began to grow up two distinct classes of practise with regard to lighting, which have been designated "general illumination" and "local illumination." The use of the incandescent lamp favored local illumination, because of the relatively inefficient units then available. The use of the arc lamp favored general illumination because of the inherent high capacity of the unit. The breach between the two methods of lighting appeared to be widening until the advent of the tungsten filament lamp provided an intermediate sized efficient unit. To-day there are certain problems which distinctly favor localized illumination, while others can best be solved by general illumination. In the majority of mill lighting problems, however, neither of these extremes provides the best solution. The tendency to-day is to provide a relatively even intensity of illumination with moderate sized units which can be arranged to concentrate the intensity where desired, and also to provide suitable direction of light. There are still some processes which require the use of localized illumination from a portable lamp to insure proper penetration of light. In all probability, this extravagant method of illumination will always be required in a few special cases. Localized lighting, however, is being used to-day in a great many places where it might much better be replaced by a semi-general illumination from more efficient lamps installed out of the workman's reach. The portable lamp is expensive to install, inefficient, subject to breakage and, furthermore, attracts the workman's attention from his work. As usually employed, it gives an uneven glaring light which tends to harm the operative's eyes and makes him demand an excessively high intensity. One permanent lamp will often replace a half-dozen or more portables.

COLOR.

In a paper read before the Society about a year ago, the author devoted his entire attention to color. In the present paper, therefore, this subject is not considered in detail. Ordinarily, it is sufficient that the color of light should approximate daylight,

near enough to make objects appear natural. It is desirable that the variation from white should be toward yellow, which is more agreeable than blue or green. In special cases, such as textile and other dye rooms, where color matching is required, an especially close approximation of daylight is necessary.

INTENSITY.

The intensity or quantitative element of illumination bears a close relation to the cost, and from that standpoint is particularly interesting to mill operators. It should be remembered, however, that intensity taken alone is not a final measure of the seeing value of any illumination. The other considerations which have already been mentioned all have a bearing on the subject and should be properly considered. To a certain extent, there is a variation in present practice and opinion as to the intensity of light necessary for particular processes. As already stated, particularly in textile mills, the color of the goods and other local conditions effect the intensity required. The following figures will give an approximate idea of the intensities used in present practice. In interpreting them for any particular problem an estimate should be made of the grade of lighting required.

Process	Foot-candles
General work with drop lights	¾ – 2
Machine-shop, no drops	2 – 4
Machine-shops, fine work	3 – 6
Warehouses and store rooms	1 – 3
Passages	¾ – 1
Weaving	3 – 6
Spinning	1 – 4
Carding	1 – 3
Breaking	1 – 2

THE BUILDING.

Building construction is a factor which does not always receive proper consideration in the designing of a lighting installation. Many of the older mills have low ceilings with wide floors which are rather difficult to light satisfactorily. It is not uncommon to find ceilings as low as 8 feet. The modern mills, as a rule, have heigher ceilings. In ordinary rooms and side bays the ceiling heights vary from 10 to 20 feet. Crane bays usually vary from 25 to 60 feet in height. From 12 to 15 feet is a very common height for an ordinary mill room; 16 to 20 feet for a side bay, and 30 to 40 feet for a crane bay.

Overhead cranes, shaftings, belts, etc., are likely to modify the arrangement of lights. Crane bays must of necessity either be lighted from the sides or from above the crane. Unless the crane is very high, and the bay very narrow, the tendency is to place the lamp above the crane, directing the light downward with suitable reflectors. The arrangement of lights along the sides of high bays sometimes causes a waste of light, due to the absorption of dark walls. Lights also have to be shielded so as to keep the glare from the eyes of the crane operator. When lighting from above the crane, it is desirable to provide an illuminant which will throw a relatively large proportion of its light downward. It is also desirable to select a lamp which does not require frequent attention, as it is usually necessary for a workman to get into a dangerous position on the top of the crane in cleaning or otherwise taking care of the lamp.

The size of unit to be selected depends upon the height of the lamp and the intensity of illumination required. A proportionate relation should exist between the height and spacing of lamps; thus where lamps are hung high, a smaller number of large units or groups are preferable, while for low rooms, a larger number of smaller units should be used. Also if the height is fixed, variations in intensity should be secured preferably by using units of different capacity rather than changing the spacing. It is desirable to minimize overhead belts and shaftings to not only improve the artificial illumination but also the daylight illumination. In buildings with concrete ceilings provisions should be made for the location of lighting centers wherever they are likely to be required, before the concrete is poured. The author has often been called upon for advice in lighting buildings where the owner was compelled to go to unnecessary expense because the designer had not provided for a suitable arrangement of outlets. It is good practice now to build mills and factories with a large window area, so that daylight can be utilized for fairly long working hours. This type of construction not only transmits the daylight freely but also allows a considerable loss of artificial lighting. In clean mills where conditions permit, it is often advisable to install light colored shades over the windows, thereby strengthening the il-

lumination near the sides of the room and providing the diffusion. An illumination test in a clothing factory showed a gain of 10 per cent. in the illumination on the horizontal working surface 8 feet from the window when the shades were drawn. The additional light was rendered more than ordinarily valuable by its diffusion and direction. It is advantageous when possible to provide light colored walls and ceilings to reflect and diffuse the light. Many mills make it a practice to whiten their walls at least once or twice a year. In a large room where various processes are carried on, it is good practice to have the artificial illumination slightly stronger in the parts of the room near the windows. In arranging the room for daylight operation those processes which require most light are placed near the windows, so that a more intense illumination is likely to be required there than elsewhere. Arrangement of lighting depends to a certain extent upon the arrangement of pillars and ceiling girders. The location of outlets should be symmetrical so as to make a good appearance and avoid post shadows. If tungsten-filament lamps are used, the size can usually be selected to correspond to the construction.

ILLUMINANTS.

It is not expedient to discuss in this paper all the various types of lamps used in mill lighting. Each lamp has its peculiar advantages and limitations. No one unit is the best for all classes of lighting. The author has been asked to discuss particularly the use of tungsten lamps with metal reflectors. The economy diffuser was probably the first of the metal reflector equipments to follow the development of the tungsten-filament lamp. With this diffuser five or six lamps, not exceeding 100-watt capacity, were grouped under a concentrically corrugated reflector, either 26 or 40 inches in diameter. A diffusing globe was provided to reduce the glare from the bare-filament lamps. In general practise it was found that the globes collected considerable dirt, so that there was a tendency to remove them. The grouping also reduced the efficiency by cutting off light. There has been a tendency lately toward the use of single-light diffusers which preclude this trouble and also decrease the maintenance cost through the use of larger lamps. An excellent in-

stallation using the economy diffusers is the Adler clothing factory in Rochester. In the installation on the fourth floor, the 40-inch economy diffuser is used with 3 100-watt and 3 40-watt tungsten lamps. With a consumption of 1.8 watts per square foot they were obtaining 6.5 foot-candles, or 3.6 useful lumens per watt. The measurements were made over a year after the installation was put in.

There are a number of excellent makes of steel reflectors which have reflecting surfaces of aluminum matte, porcelain enamel, etc. The dome type porcelain enamelled reflector is used to good advantage in the Deering Harvester works in Chicago. The so-called selective diffusing reflectors are made in two sizes 16 and 21 inches in diameter. The 16-inch diffuser, has a 2¼ inch collar and is intended for use with tungsten lamps up to and including the 250-watt size. The 21-inch diffuser has a 3¼ inch collar and is intended for use with 250-, 400- and 500-watt tungsten lamps. At first these diffusers were finished with paint enamel on account of its highly efficient reflecting surface, but as the surface did not last the advantage of this efficiency was soon lost. The finish has since been changed to porcelain enamel, and the high efficiency has been retained by the use of an unusually heavy coating of white enamel. An illumination test was made with 250-watt tungsten lamps equipped with 16-inch diffusers as installed in the induction motor department of the General Electric Company in Schenectady, N. Y. This building is about 60 feet wide and is divided into three bays; the height of ceiling is 24 feet, the height of lamps is 23 feet; the consumption was 1.02 watts per square foot; an illumination on the working level of 4.8 foot-candles, or 4.7 lumens per watt, was obtained. The lamps were suspended beneath a gray concrete ceiling, and subsequent tests showed that substituting 21-inch diffusers increased the average illumination on the working level about 8 per cent.; while the use of the 16-inch diffuser gave 21 per cent. more light than when the ceiling only was depended on for reflection.

DISCUSSION.

Mr. George S. Barrows:—I should like to ask Mr. Stickney

whether the glare in a steel mill, or wherever there is a white heat from hot billets or other heated metal, is really wanted, or a high general illumination in order to nullify the glare from the heated metal?

I should also like to ask whether any investigation has been made to determine whether more accidents occurred during the dark season of the year due to mixed illumination, that is, mixed daylight and artificial illumination; or whether, if there were more accidents during the dark season, they were due to inadequate artificial illumination?

Mr. Stickney:—In answer to Mr. Barrows' question regarding glare in the billet mill, I wish to say that I do not think the workmen desired as high a degree of glare from the light sources as that which came from the billets; but, in this connection, it should be remembered that a glaring light is not so apparent to the eye when it proceeds from above, as when it comes from below, as in the case of the billets. In the case which I mentioned, it was a question of determining the height of flaming arc lamps, and the workmen preferred to have them hung low.

In reference to the curve showing the larger number of accidents during the dark season, I should say there was no analysis given, and, as far as I know, no satisfactory investigation has been made.

Mr. Norman Macbeth:—The curves published in the *Illuminating Engineer* to which Mr. Stickney referred, showed very clearly that the greater number of deaths from accidents occurred during the three dark months, or months of short daylight hours. The further question as to the hour of the day in which the greater number of these accidents happened was not touched upon. I think it would be difficult, to say the least, to determine what proportion could be charged to insufficient artificial lighting. From a knowledge of workshop illumination standards at this time, I feel, however, that this very serious condition may be charged directly to this cause. This question of factory illumination is neither a simple problem nor one upon which there is much conclusive data. The further the investigations are carried, the more one is forced to realize the depth of the prob-

lem and the comparatively small amount of reliable data now available. Generally speaking, the illumination is about one-tenth of what it ought to be; consequently there is a practically undeveloped field of great promise for the industrial plant owner, the lamp and accessory manufacturers and the electric or gas companies supplying energy.

I was very much interested a few days ago in going over some reports of installations recently completed in the East Pittsburgh works of the Westinghouse Electric & Manufacturing Company. They have installed about 7,000 tungsten-filament lamps in the last year and a half, and have kept very complete records. Regular and frequent inspections are made of these lighting systems, and the conclusions and deductions from the figures secured were exact and extremely interesting.

One interesting point which was brought out through considerable experiment was that the men preferred glass reflectors rather than metal reflectors so frequently used in this work. It was found that the maintenance of the glass reflectors was high, but not higher than it would be with metal reflectors, which have to be cleaned as often as the glass. It was necessary to clean any of the reflectors used at various periods, depending upon the shop conditions, from twice a month to once in two months. The depreciation values secured were similar to those given here by Mr. Stickney, as high as 40 to 50 per cent.

The question of increasing the effectiveness of these installations should be brought to the attention of managers and owners of industrial plants. Mr. Stickney has worked out the comparative cost of a lighting installation with the cost or value of the output. Another basis is on that of the wages paid. I doubt very much whether one can appeal to a man solely on the basis of prevention of accidents or the conservation of eye-sight. Unfortunately they feel that if one man cannot do the work there is another to take his place. Considerable importance should be attached to the question of turning out more and better work and on the time saving elements. The added costs for an installation of satisfactorily high intensities will figure out less than 5 per cent. and seldom means more than 2 per cent. of the

yearly wages; this frequently means that a saving of two to four minutes of a man's time per day will more than pay for the increased illumination. It is not hard to compute the saving in an industrial plant in a year on that basis.

Mr. T. J. Litle, Jr.:—In regard to the placing of units in a machine-shop, I notice that even the illuminating engineer sometimes makes a mistake and that often the workmen can give him some pointers. Sometimes a lathe will be lighted from a direct-tion to the right of the worker, or above his head; that suffices where he is turning out straight flat work, but where he is boring out a cylinder, it is a different problem. In one case I saw a man with a 16 candle-power lamp above his work and a tallow candle near him. His reason for using the combination was that with certain work he required the 16 candle-power lamp, and on other work he needed 17 candle-power, which he got by adding the candle.

The workman often requires a flexible support for his lamp in cases where it is necessary to shift his light source, and in boring with a chuck this is often required. One way to accomplish this is by the use of cords.

Regarding the glare, I think it is almost criminal to place a lamp of the type before us this evening in rooms having low ceilings, without protecting the lamp in some way. I suppose Mr. Stickney would not propose using this lamp lower than 9 or 10 feet from the floor. With this glare, one's eyes are momentarily paralyzed, and a workman walking down the room after looking at one of those lamps would be apt to stumble over any object in his path.

Regarding the intensity of illumination, I think the requirements are becoming higher. General illumination is necessary in a workshop, but local illumination is just as necessary.

Mr. Stickney:—In my talk I stated that there are a number of processes, which, in all probability, always will demand local illumination. The case mentioned by Mr. Litle, namely, boring out the inside of a cylinder is an example of this. The working illumination can be better applied by means of a small local lamp. Mr. Litle objects to the glare of the bare tungsten lamps, as I have had them installed in this room, and

I agree with him that under these circumstances the glare is offensive. I have seen a large number of installations where similar lamps were installed at corresponding heights in industrial plants, and the glare was not serious. When such installations were first introduced the use of frosted bulb lamps or diffusing globes was insisted upon, but they were never used for a long period of time. When such a lamp has been installed in an industrial plant for a few days, dirt and dust accumulates, which reduces the glare. When frosted lamps or diffusing globes are used, the loss of light from the accumulation of dirt is so excessive that very few will permit their use.

Mr. E. G. Perrot:—There is one phase of the illumination problem I do not think Mr. Stickney brought out. In practice one sometimes finds that illumination costs practically nothing. I have in mind a manufacturing plant which requires so much steam in the process of manufacturing to which it is devoted, that when it is necessary to use the lights, the steam from the engine which runs the generators goes into the drying system and is used in the process of manufacture, so that the lighting is obtained for next to nothing.

The question of how much energy would have to be expended to give the proper amount of illumination in a building of that kind, is not a serious one; one may provide for as much as wanted, inasmuch as live steam has to be furnished in the process of manufacture. It is largely a question of up-keep more than anything else.

Mr. John R. Keenan:—I would like to find out what the candle-power of a 500-watt tungsten lamp, with the reflector, is directly beneath the lamp?

Mr. Stickney:—The light intensity directly downward from a 500-watt tungsten lamp equipped with one of the 21-inch reflectors mentioned in my paper is about 600 candle-power.

The discussion has brought out some interesting points. One point, however, though theoretically true, does not always follow in actual practice. I refer to the question of maintenance cost of carbon and tungsten-filament lamps. In fact, it very often figures out in maintenance alone that tungsten lamps are considerably cheaper than the carbon filament, especially where

the latter are used in clusters. One moderate-sized tungsten lamp, say 100- or 150-watt, will often replace a half dozen or more 16-candle-power lamps. This makes a relatively low first cost of lamps, which, taken together with the longer useful life of the tungsten lamps, as compared with the carbon, will often show a considerable saving independent of the cost of power.

Mr. Barrows:—I would like to ask Mr. Macbeth a question. He said, I believe, that the workmen preferred glass reflectors; I would like to know why they preferred them; he did not say.

Mr. Macbeth:—The reflectors used were mostly prismatic glass, some opal, and I understand the decision was in favor of the glass, because of the more cheerful appearance of the various work-rooms. In locations where the ceilings were light, the efficiency was somewhat higher than would be the case had metal reflectors been used. There is no particular advantage in the metal reflector, that I know of, although it might be assumed that the reflecting surface would be equal in efficiency to that of the glass, and consequently that 25 or 30 per cent. of the light going through prismatic or an opal reflector into the upper hemisphere would be, with the metal reflector, re-directed into the lower hemisphere, giving the metal reflector a higher utilization efficiency. This theory, however, was not borne out by the tests.

Mr. R. B. Ely:—In connection with the lighting of shop work, engravers and printers frequently want to print a section of a plate, and in order to designate that section they scratch a line directly on the plate. In order to see the scratch or line, they try to have the glare reflected directly into the workman's eyes, so that he can put his card or paper right on the line. In connection with the work of polishing silver and buffing shoes, etc., is it desirable to use general illumination entirely or to localize the light so that the man will get a glare on his work to enable him to see the scratches or rough surface?

Mr. Stickney:—There are a great many processes, such, for example, as the truing of electric meter disks, or the grinding of lenses, in which inspection is made by means of light reflected from polishing surfaces. These require the use of light sources so located as to be available for direct reflection to the work-

man's eyes. The best results are often obtained by continuing with the light source to which the workman is accustomed. Sometimes bare filament lamps are used and sometimes diffusing glasses. In some cases it is desirable to have a regular pattern drawn on the diffusing glass to show by distortion whether or not a surface is true. Most of these cases are so special that they can be handled to better advantage by the foreman, who understands the requirements of the process, than by an illuminating engineer.

Mr. J. D. Israel:—If I remember correctly, a question was asked as to whether anything had been developed in the electric field for distinguishing different shades of material for colors. I think the carbon dioxide vapor lamp will answer that purpose; it is used in dye works and other places where a fine distinction is required between color shades.

Mr. Stickney:—The carbon dioxide tube, although it has some other limitations, gives a very good quality of light for color matching. About a year ago, or a year and a half, the Schenectady laboratory of the General Electric Company at the urgent request of a woolen milling company, undertook the production of a color-matching light for dye rooms using the enclosed arc lamp. A hood reflector was provided with a selective blue glass window at the bottom, but the most difficult problem was that of finding a combination of glass which would eliminate the excess of red and yellow rays in the right proportion. Two sample sets were supplied to this woolen company and are still in use in the dye rooms of two of their mills, giving satisfactory results. Since these were furnished further experiment has improved the efficiency of this scheme by reducing the light absorption in the glass, so that the equipment seems to be very well suited for this purpose. Experiments have also been carried on in Schenectady, and I believe in Cleveland, to secure similar results from the tungsten lamps. No report has yet been made of the Schenectady tests. The tests which were made in Cleveland were described in an article by Dr. Ives and Mr. Luckeish, in the *Electrical World* for May 4, 1911, from which it appears that a very close substitute for average daylight has been obtained from the tungsten lamp, with a consumption of about ten watts per candle.

Mr. Israel:—I have heard a great deal on this subject from the electric standpoint, and I would like to ask our fellow members from the gas company if they find similar conditions obtaining in the use of the large and the small gas units; and also if there have been any experiments with any form of indirect gas lighting?

Mr. Macbeth:—In the gas field the larger units are perhaps used to a greater extent in work-shop illumination. Many of the lamps are equipped with opal and opaline globes and are installed generally on some form of contact which insures frequent cleaning of the lamp glassware and parts. Three-, four- and five-mantle lamps are used considerably, while quite a number of the 50-candle-power inverted lamps have been installed. The tendency is somewhat towards the smaller unit, while the lamp manufacturers are working along development lines to fill in the gaps from the smaller 20-candle-power lamps up to meet the multiple mantle sizes.

Some work has been done in indirect lighting with gas lamps, and while numerically there are fewer indirect gas than electric installations, it is possible that the percentage of new indirect installations may be as large with gas as with electric lamps.

Mr. Litle, Jr.:—It seems to me that if a factory has a white ceiling indirect lighting is just as efficient there as in a store. General illumination in a factory is not necessarily the most efficient. The machines themselves are, I think, in most cases, lighted independently of the general illumination, because certain parts of the work need higher illumination than others. I do not think there is a bit of difference in the problem of the illuminating engineer, whether he is dealing with gas or with electricity.

Mr. W. J. Serrill:—I understand that the dust on the reflectors is the greatest foe to indirect lighting, and I suppose that in factories there is more dust than in offices or other rooms.

Mr. G. B. Muth:—As Mr. Stickney has said that the builders of concrete buildings do not give proper consideration to the lighting possibilities, and as Mr. Perrot has had large experience in planning concrete buildings, perhaps Mr. Perrot will say something on this point.

Mr. Perrot:—My practise has been to prepare for the lighting before the erection of the building. In other words, the lighting scheme is laid out and contracted for simultaneously with the letting of the contract for the building, and the electrical contractor is obliged to put in his sockets and sleeves before any concrete is poured. Provision is also made in the design of a building for extra pipe sleeves in case there is to be a change of position of pipes or conduits, as there generally is in the development of a plant. If the machines are moved, the lighting scheme frequently has to be changed. Provision is made in the construction for the use of Malbage iron sockets for lighting fixtures, overhead shafting or the like, which checker-boards the ceiling in squares of about 5 ft. in each direction. These sockets are flush with the bottom of the beams and are tapped for ¾ in. or ⅞ in. bolts, as the case may be. In buildings of a mercantile character, where the conduits have to be concealed, these are put in the filling between the top of the concrete floor and the finished floor. There is generally a 2 in. or 3 in. space filled in with cinder, concrete or other material, and the conduits are put in this space. Of course the outlet boxes have to be put in the solid concrete, and these and holes for vertical conduits are the only things necessary to be put in before the concrete is poured.

An iron socket about 1½ in. long tapped for about ¼ in. machine screw is also used. It is placed in the floor slab, whereever it may be necessary to have a line of conduit. These small electrical sockets are put in the ceiling and cannot be seen, and in that way save the mechanic from drilling the concrete. The whole problem, to my mind, is a little foresight in the design of the building.

A CORPORATION GRADUATE COURSE IN ILLUMINATING ENGINEERING.[1]

BY SYDNEY WHITMORE ASHE.

The purpose of this paper is to outline a graduate course in illuminating engineering which was inaugurated about a year ago by a large manufacturing company for the benefit of a number of recent college graduates who entered its employ to be trained as electric incandescent lamp specialists. In the synopsis of the course as given below three topics are discussed briefly: first, the necessity of the course; secondly, a review of the course; and lastly, the results accomplished.

Necessity of the Course—Two points in connection with the genesis of this course should be mentioned if not emphasized: illuminating engineering has had a rapid growth recently, and is yet a new field; secondly, technical schools and colleges have not had ample facilities to conduct a course of this kind. To give proper instruction in illuminating engineering a school requires considerable apparatus and the coöperation of a corps of specialists. Suitable instructors, space for the apparatus, and the time in which the instruction may be given are also important considerations. Moreover, the scope of such a course if it be at all comprehensive is necessarily broad. The ground which must be covered was exemplified by the course in illuminating engineering given under the auspices of this Society at Johns Hopkins University last fall. It is not at all surprising therefore that few technical graduates of the present day have little more than a superficial knowledge of illuminating engineering. In discussing this particular topic recently at a meeting in Boston of the Society for the Promotion of Industrial Education the author summarized the conditions which necessitated the present course in illuminating engineering as follows:

The necessity for a corporation school for college graduates arises from the fact that for four years the average student has been accustomed to absorbing knowledge, to having his program definitely ar-

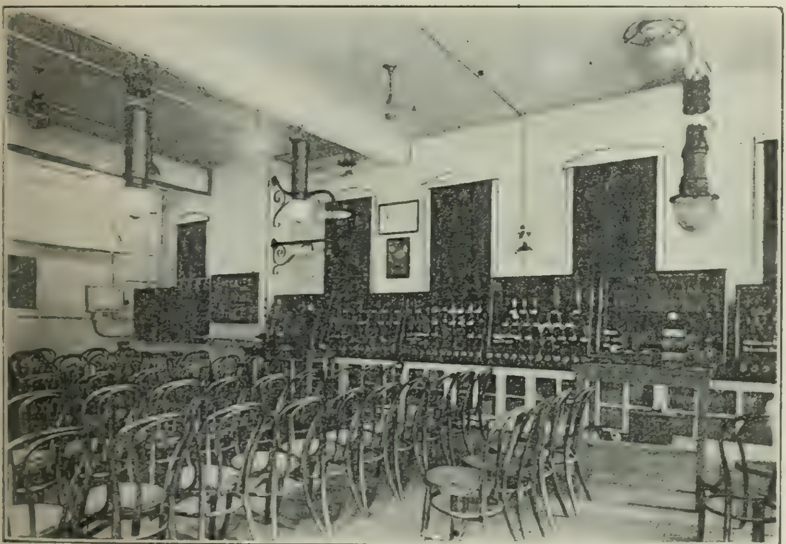
[1] A paper read at a meeting of the New York section of the Illuminating Engineering Society, June 8, 1911.

ranged for him, and having someone behind him to push him; in other words, the whole atmosphere has been one of absorption. When the young man enters a corporation the process is reversed; it is one of giving out instead of taking in. The young man feels lost; he is not accustomed to seeking work; he is not accustomed to arranging his own program; he lacks initiative; he lacks the faculty of going to the bottom of things; he lacks the ability of accomplishing results, and he lacks a knowledge of commercial procedure and departmental methods. Accordingly his first year must be one of readjustment. While in school he felt that he was somewhat of a demagogue; in the corporation he feels that he is a non-entity: it is hard for him to produce as a part of a whole when formerly he worked as a single unit. To familiarize him with this new mental procedure and readjustment, therefore, it is necessary to look after him, to keep up his enthusiasm, to keep up the spirit of good fellowship and still have him become accustomed to the company discipline.

A Review of the Course—About forty-three college men were selected early last spring from various institutions throughout the country. About the middle of August they had all reported at the works of the company. Systematic instruction has begun at once. The men were assigned to various parts of the manufacturing and development laboratory. Later they were transferred to different departments; so that they were thus able to gain during the year a comprehensive knowledge of the manufacture of incandescent lamps.

For the first few months these men assembled in the lecture room each day from eleven to twelve. There they were given a thorough training in the theory of illumination, lamp manufacture, and salesmanship. Each man at some stage of the course was assigned a topic upon which he was required to prepare an hour's talk. This afforded an opportunity to study the personality of the man and also assisted him in specializing on some particular subject. As the course progressed and the men became more settled in their occupations, the number of lectures each week was reduced. At the end of seven months only two lectures a week were given. These were considered sufficient to maintain the educational atmosphere. In the forepart of the course most of the instruction was conducted by men in the company, but after the men had gone over the subject quite thoroughly many outside specialists were invited to lecture on various subjects.

The lecture room where the educational work was conducted, was well equipped with many forms of demonstration apparatus. Various arc and incandescent illuminants, including several types, of gas and mercury-vapor lamps, luminometers; photometers and gas meters were in use. There was also available the usual assortment of ammeters and voltmeters. These facilities for instruction were augmented by the proximity of the factory, sales, and commercial engineering departments. From



A view of the lecture room.

the latter departments all the parts of lamps, contract forms, various sales data, and numerous data on illuminating engineering could be procured immediately.

Supplementing the instruction in the lecture room and in the company's organization, occasional excursions were conducted to various lamp factories, the power stations of the New York Edison Company, the Interborough Rapid Transit Company's power houses, the Holophane Company, and other companies in the vicinity of New York.

The advisability of giving laboratory work and having the men carry on special research work was also considered, but such work was not deemed feasible at the time.

By meeting the men from day to day and also studying them while at work in the factory, it was possible to ascertain the special aptitude of the men for any particular line of activity. Those who showed an inclination for research work remained in the development laboratory, those who showed a liking for factory work were of course assigned to the factory, and those who exhibited a special fitness for salesmanship or commercial engineering were placed in the sales department.

Results Accomplished—The aim of the course was to give the best all-around course in illuminating engineering ever presented. How well this plan has been carried out is indicated by the appended list of the lectures delivered during the course. Just what results have been accomplished it is difficult to state definitely. The course is still in progress. All the men, except two who have dropped out, have been assigned to various departments of the company. It may be conjectured, however, that the ultimate results can not be but very gratifying to both the company and the men.

PARTIAL LIST OF LECTURES DELIVERED IN CONNECTION WITH COURSE IN ILLUMINATING ENGINEERING.

COMMERCIAL.

Subject	Lecturer
Sales Organization in Large Central Stations	T. I. Jones
Central Station Salesmanship	Clarence L. Law
The New York Edison Company's System	A. H. Lawton
Reminiscences	C. D. Haskins
Salesmanship	F. M. Kimball
The Test Course	A. L. Rohrer
Publication Bureau	M. P. Rice
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NOTES ON COMPARISON OF ILLUMINANTS[1]

BY SYDNEY W. ASHE

Consideration of a Basis of Comparison—Whether two illuminants should be compared in terms of actual lumens emitted or according to particular usefulness is a question worthy of serious consideration. It would not be fair, for instance, to attempt to compare for street lighting a magnetite arc lamp and a tungsten lamp on the total lumens basis, because the magnetite arc lamp has certain peculiarly suitable characteristics of distribution, such as sending out its maximum lumens between a 90° and 75° angle, that afford very effective street illumination. On the other hand, for interior illumination, such as stores, mills, etc., it would be perfectly fair to compare these lamps on the basis of total lumens. As the magnetite lamp must operate with a series resistance on a multiple circuit its comparison with the incandescent lamp in the latter case is, of course, not as favorable as in the case previously cited. Whether an inverted unit has a more preferable distribution than an upright illuminant is another question often discussed when the relative merits of two illuminants are considered. For many years candles were burned in upright positions, but when the incandescent lamp appeared it was burned in an inverted position, which was believed to be a great advantage; but to-day in many homes a tendency to burn the incandescent lamp in an upright position is noticed. And there is no doubt but that there are many advantages to be gained by equipping an incandescent lamp with a reflector which will distribute the light where it is most needed and increase the efficiency of a given illumination to the maximum. Then, too, there are lamps, such as the Nernst lamp and certain types of inverted gas lamps which have a decided downward distribution of light, and whose loss of light due to absorption of reflectors may be practically negligible. All these conditions and difficulties, as well as numerous others, beset the investigator who endeavors to adduce a satisfactory basis for the comparison of illuminants.

[1] A paper read at a meeting of the New York section of the Illuminating Engineering Society, June 8, 1911.

Average Candle-power Performance—a Basis of Comparison—The author wishes to recommend for general use a suggestion which has been made by others, that two illuminants be compared on their average candle-power performances throughout life. That is what the consumer pays for, and it seems that this is the only fair basis of comparison. If this paper aids in any way the adoption of this method of comparison, the author will feel it has accomplished its mission.

The average performance takes cognizance of all of the variable candle-power characteristics of the illuminant. For instance, many gas mantles have peaked candle-power life curves. Mercury-vapor lamps on the other hand have a curve which continually falls away. The decrease is marked at first, and then becomes more gradual. Electric arc lamps have a gradual decrease during the life of the electrodes, due to the formation of dust in the globe.

Tungsten Filament Incandescent Lamp—The development of the tungsten-filament lamp has done much to improve the general illumination of large cities. This lamp, including the cost of renewals, gives about two and one-half times the light for the same price as the old carbon lamp. It has found a ready access into outlying territories which beforehand could hardly be illuminated with carbon lamps. Furthermore, with the introduction of the high candle-power or the 400- and 500-watt units, this lamp has replaced, in many cases, the old multiple type of enclosed carbon arc lamp. The increase in the use of this lamp has been so large—last year it was fully fifty per cent.—that a study of the candle-power performances of at least two of these units is interesting. The metal filament of the lamp having a high vapor point does not disintegrate as rapidly as the carbon filament. Consequently the life of the lamp is not only much greater than that of the carbon lamp, but its average candle-power performance is higher. In figs. 1 and 2, it will be noted that the curves peak slightly, and that the average candle-power performance of the lamps compared with initial candle-power is quite high. Ninety-four per cent. (on

a basis 1,000 hours) may be considered a conservative value for

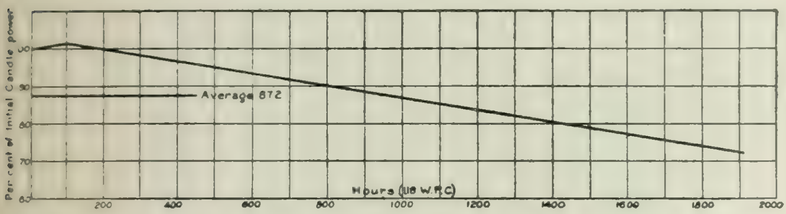


Fig. 1.—Average candle-power life curve of 60 watt 100 volt drawn-wire tungsten lamp. (Average of 60 lamps tested in laboratory.)

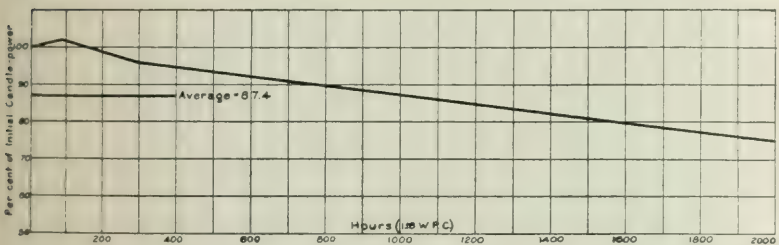


Fig. 2.—Average candle-power life curve of 100-watt 100-volt drawn-wire tungsten lamp. (Average of 24 lamps tested in laboratory.)

the average candle-power performance throughout the life of these units.

Gas Lamps—Obviously it is very difficult to assign a conservative value for the average candle-power performance of gas mantles. Almost every manufacturer of mantles makes a large number of different grades of mantles varying from the most expensive to the cheapest. Many mantles, also, are used on different types of lamps. Furthermore, where in the United States can two plants be found that manufacture and deliver gas of the same quality and pressure? And when the point of photometering a mantle is reached any results pertaining to candle-power life which might be obtained will be affected by burner adjustment, shrinkage of mantle, variation in pressure of gas, calorific value of gas, humidity, room temperature, etc. Even when all these conditions are considered there still re-

mains the question of rating gas lamps. Heretofore, the lamps have had, similar to the rating of arc lamps, a "nominal" candle-power rating. For instance, it has been stated that a gas lamp gave so many candle-power. Whether this value represented the maximum radii of its distribution curve, or just what it meant, is hard to say, except that it conveyed a wrong impression to the buyer. This difficulty, however, is being rapidly remedied at the present time by the more progressive manufacturers of gas lighting devices. Moreover, gas engineers are resorting to the modern method of publishing distribution curves of lamps, which give the values of the total lumens as well as the lumens in the various zones. The old method of rating gas lamps has been, and is to-day wherever it is employed, detrimental to the best interests of the gas industry. For example, in the *Electrical World* of August 18, 1910, are given the following values of a test on gasoline street mantles, in Chicago, under the direction of the Merrian Commission, by J. R. Cravath:

Test number	Horizontal candle-power
36	21.1
37	19.3
38	54.0
39	58.4
39	65.2
40	27.1
41	16.8
42	24.0
43	17.0
44	24.5
45	19.8
46	14.0
47	28.0

These lamps were supposed to give 60 candle-power according to their method of rating. It should be noted that the commission interpreted this as representing horizontal candle-power, with the result that only three of the tested lamps were anywhere near this value.

In the *Electrical World* for September 2, 1909, page 538, Dr. Louis Bell published a list of candle-power values of gas lamps which he photometered in Boston:

Lamp No.	Candle-power	Lamp No.	Candle-power
1	42.6	10	24.5
2	30.7	11	25
3	16.6	12	24.2
4	40.8	13	34.3
5	66.3	14	30.6
6	31.5	15	34
7	24.5	16	32.5
8	26.5	17	24.8
9	29		

Dr. Bell stated that the lamps were not selected with a view to getting high or low candle-power values. These lamps, too, were supposed to give 60 candle-power. It will be noted, though, that their average was only 31.7 candle-power.

Mr. Norman Macbeth has published[1] data of actual installations of gas lamps designed and tested under his directions.

Equipment	Areas sq. ft.	Intensity foot-candles	Useful flux lumens
Frosted tip cylinder clear reflector	685.5	4.25	2915
Sand-blasted globe	1350	2.6	3310
Frosted tip cylinder clear reflector	2573	2.5	6450

Equipment	No. of burners	Effective lumens per lamp actual	Effective lumens per lamp rated	Per cent. of rating
Frosted tip cylinder clear reflector	12	243	363	67.0
Sand-blasted globe	16	219	273	79.6
Frosted clear tip cylinder reflector	18	230	263	63.4

The average value obtained in these three tests was 70 per cent. of the rating of the lamps.

In the TRANSACTIONS of the Illuminating Engineering Society, April, 1909, Mr. Preston Millar made the following statement as the result of the number of tests and observations which he had made:

> My experience is that the average candle-power performance of street lamps is from 60 to 70 per cent. of the rated candle-power as shown by long laboratory tests. It shows what we must take from the laboratory efficiency of the gas lamp.

In arriving at a conclusion, therefore, as to what should be taken as the average performance of the gas mantles in use to-day, the author feels that 70 per cent. is a conservative value, taking all the various phases and data at hand into con-

[1] *American Gas Light Journal*, Oct. 11, 1909.
Proc. Am. Gas. Inst., vol. IV, p. 305.

sideration. There is no doubt but that there are many high-grade gas mantles made to-day which, when burning under ideal conditions, give values of average performance which are higher than this. On the other hand there is a very large number of mantles for which the above rating would be altogether too high.

Pilot Gas Flames—Owing to the uncertainty of the published data on pilot flames of gas lamps, a series of tests was made on a few burners purchased in the open market to determine their consumption. Before beginning the tests there was at

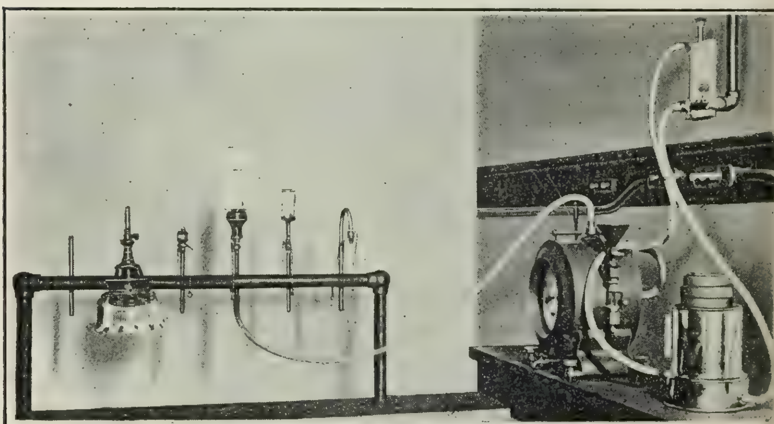


Fig. 3.—Apparatus for measuring consumption of pilot gas flames.

hand a standard gas meter, a governor, a varied assortment of burners, pilot tubes, a pressure gauge and a stop watch. This apparatus was arranged as shown in fig. 3. A number of small tubes passed through the central support in the apparatus, so that a burner could be attached to the upper end and the gas tubing to the lower end. The pressure gauge read one-eighth inch and was connected by means of the rubber tubing to a glass tubing in the main lines. Four different pilot flames were tested: an ordinary pilot flame for reflex burner, a pilot flame for Welsbach junior lamp, a pilot flame for Gem open burner, and a Welsbach turn-down burner. In each case the gas consumption for five different pressures was taken and the average of at least

five different readings was obtained. The heights of the flames were first adjusted under normal pressure, so that they were at a minimum.

The average readings and curves of average value (figs. 4, 5, 6, 7) are given below. The approximate height of the pilot flame is also given. The values are self explanatory.

CONSUMPTION OF PILOT FLAMES.

Pressure	* Cu. ft. per hr.	Height
	Welsbach upright turn-down attachment	
1.0 in.	0.343	
1.5 in.	0.367	
2.0 in.	0.449	
2.25 in.	0.455	
2.5 in.	0.506	
	Welsbach Jr.	
1.5 in.	0.0476	1/16 in.
1.0 in.	0.0265	1/32 in.
	Gem burner	
2.5 in.	0.0686	1/8 in. slightly yellow
2.25 in.	0.0628	3/32 in.
2.0 in.	0.0546	
	Reflex pilot flame	
2.5 in.	0.212	1/4 in. yellow and blue
2.22 in.	0.1898	
2.0 in.	0.1747	
1.5 in.	0.1361	
1.0 in.	0.0944	

* Values recorded are means of five or six observations.

The Gem burner, which was an open burner, was the only one which could be found at the time on the market, whose pilot flame was extinguished when the main burner was turned on.

Mercury-vapor Lamps—In order to compare the mercury-vapor lamp with other illuminants, it is necessary to decide upon some basis of estimating the total light flux. Various empirical formulae have been suggested, one of which was recently presented before the society in an excellent paper by Dr. J. C. Pole. The trouble, however, with using such equations is, that it is difficult to give physical conceptions to the various component parts of the equations, and consequently they are unintelligible to the ordinary layman who is expected to

use them. It is preferable, therefore, to lean toward the old method of integrating the total flux in which the mercury-vapor tube is considered as a point light source and photometered at a distance of about twenty feet. The author emphasized in discussing Pole's paper that this distance eliminates errors from considering the tube as a point light source, and also eliminates errors due to the Purkinje effect, provided the average mean spherical candle-power is determined in three planes and the

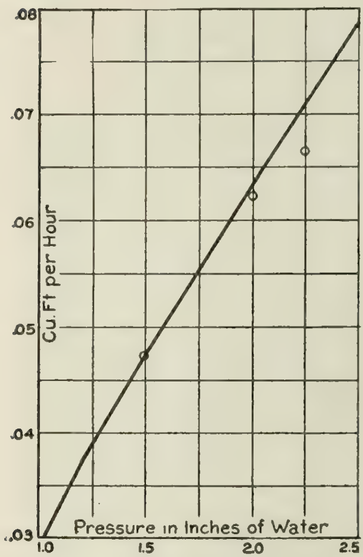


Fig. 4.—Welsbach Junior pilot tube flame consumption.

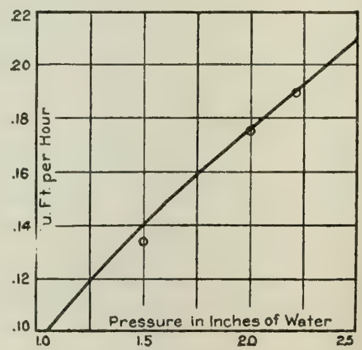


Fig. 5.—Inverted pilot tube flame consumption.

final average taken. The latter value multiplied by 4π gives the total lumens, which, from measurements of the apparent lumens made by the author, appear to be quite constant, excepting when measurements are taken within a few inches of the tube.

Especial attention is directed to the accompanying photometric curves of the mercury-vapor lamps. The curves of figs. 8-15 represent measurements taken in one plane only. In those cases the tester was unable to properly manipulate the tubes and was hampered somewhat by the size and location of the photom-

eter. The tests, nevertheless, were made in a well equipped engineering laboratory and, although only one tube was tested

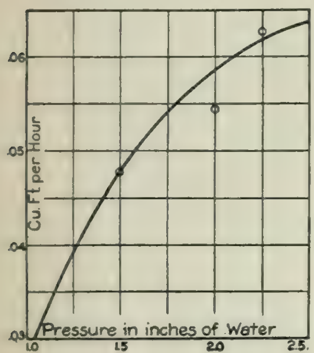


Fig. 6.—Gem burner pilot tube consumption.

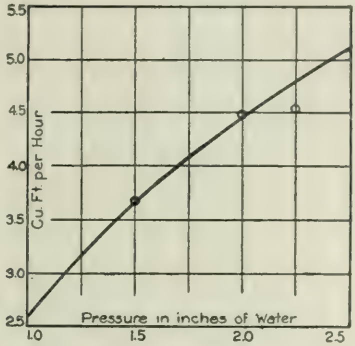


Fig. 7.—Consumption of an upright gas lamp with turn-down attachment.

in each instance, the results as far as scientific accuracy is concerned, were the best obtainable. Figs. 8, 10 and 11 represent tests

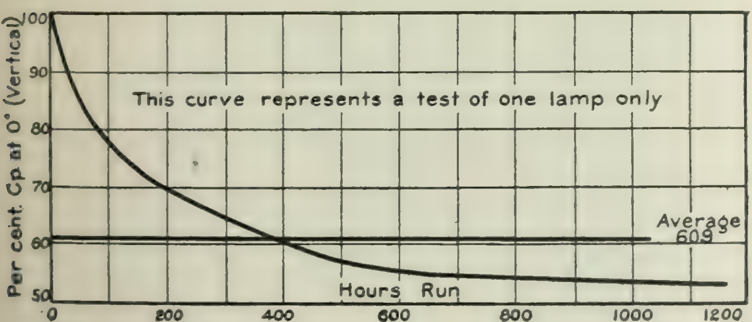


Fig. 8.—Candle-power performance of a 45-inch, 3.5-amp., 110-volt, direct-current, non-automatic, mercury-vapor lamp. Readings were taken at 21.25 ft. radius with tube at 45° to photometric axis. Lamp was equipped with a reflector and operated at 110 volts during test.

of the same lamp. Figs. 9 and 12 also were plotted from results obtained from the same lamp. Fig. 13 represents a test of a 3.3-amp. tilting-type lamp. The reduction factor equal to the theoretical value for this particular cylindrical source is 78.54 per cent.

The test indicates that 182 mean spherical candle-power was ob-

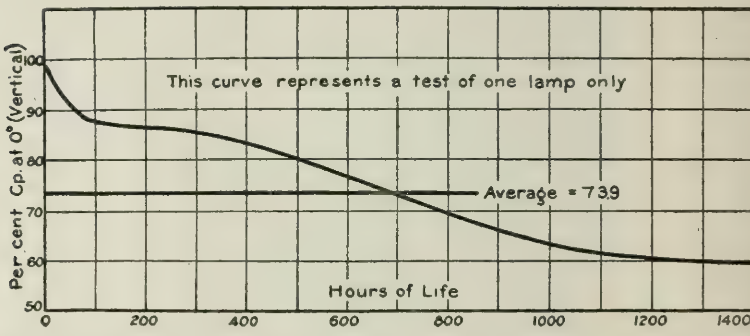


Fig. 9.—Candle-power performance of a 50-inch, 7.1-amp., 110-volt, alternating-current, automatic, mercury-vapor lamp. Readings were taken at 21.25 ft. radius with tube at 45° to photometric axis. Lamp was equipped with a reflector and operated at 110 volts during test.

tained. The curve of fig. 14 represents the maximum efficiency of the same lamp. It will be noted that the most efficient point of this lamp is 3.5-amperes. Accordingly, the mean spherical candle-

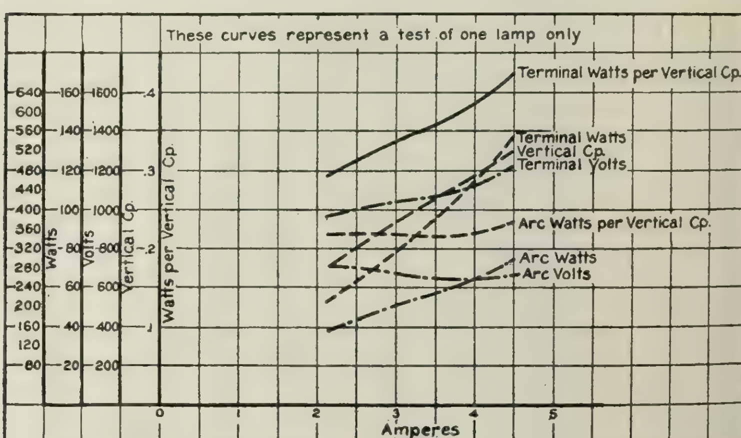


Fig. 10.—Characteristic curves of a 45-inch, direct-current, 3.5-amp., 110-volt, non-automatic, mercury-vapor lamp.

power is increased to 185, which is a conservative value for the lamp. Were the lamp equipped with a reflector the question of absorption would of course have to be considered. Mr. M. H. Vom Baur has found[1] such absorption to be as much as 19.5

per cent. A double-tube lamp, fig. 15, gives 288 mean spherical candle-power, or equivalent to 144 mean spherical candle-power for a single tilting-tube lamp, like that represented in the latter figure, equipped with a reflector. Allowing for absorption by the

Volts Terminals	110
Volts Arc	70
Amperes	3.5
Watts	385
Mean Hemispherical Cp	754
Watt per Mean Hemispherical Cp.	.51
Mean Hemispherical Cp per Watt	1.96
Mean Spherical Cp.	398
Watts per Mean Spherical Cp.	.97
Mean Spherical Cp. per Watt	1.03

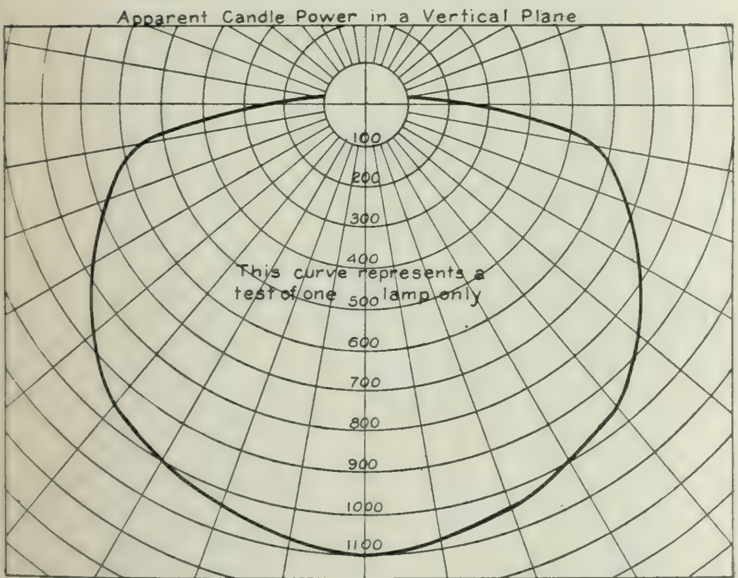


Fig 11.—Distribution curve of a 45-inch, 3.5-amp., 110-volt, direct-current, non-automatic, mercury-vapor lamp. Readings taken at 21.25 ft. radius with tube at 45° to photometric axis.

reflector the mean spherical candle-power would be 179, which is very close to the mean spherical candle-power of 182 of the bare lamp as stated above. The reduction factor of the mean spherical candle-power of a bare lamp to the mean lower hemispherical candle-power, with a reflector, is approximately 1.6. The factor for mean horizontal candle-power of the bare lamp to mean lower hemispherical candle-power with a reflector is 1.25.

[1] *Ill. Eng.*, Aug., 1906.

Tests made to determine the average candle-power performance of the mercury-vapor lamps showed a value of 61 to 75 per cent. of the initial candle-power. Accordingly, the average mean

Volts Terminal	110
Volts Arc	146
Amperes	7
Watts	425
Mean Hemispherical Cp.	888
Watts per Mean Hemispherical Cp.	.47
Mean Hemispherical Cp. per Watt	2.09
Mean Spherical Cp.	474
Watts per Mean Spherical Cp	.90
Mean Spherical Cp. per Watt	1.11

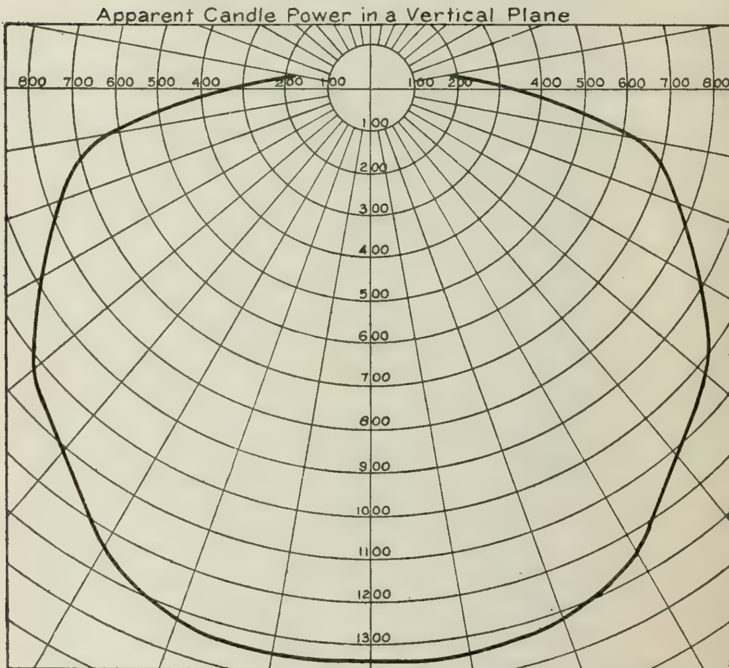


Fig. 12.—Distribution curve of a 50-inch, 7.1-amp., 60-cycle, alternating-current, automatic, mercury-vapor lamp. Readings were taken at a 21.25 ft. radius with lamp at 45° to photometric axis.

spherical candle-power of the tilting-type direct-current mercury-vapor lamp, fig. 13, is 110.

Prof. Freudenberger of Delaware College has stated[1] that the candle-power of a mercury-vapor lamp decreased 16 per cent. within the first twenty-four hours. A similar statement[2] by

[1] *Electrical World*, June 25, 1904.

[2] *Elect. Zeitschrift*, Dec. 22, 1904.

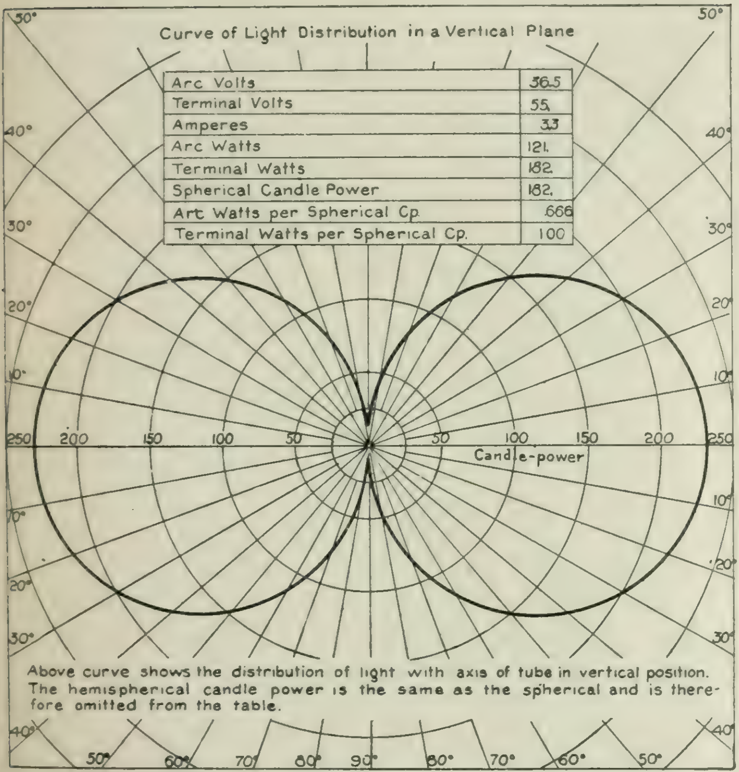


Fig. 13.—Distribution curve of a 21-inch, 3.3-amp., 55-volt, direct-current, tilting-type, mercury-vapor lamp.

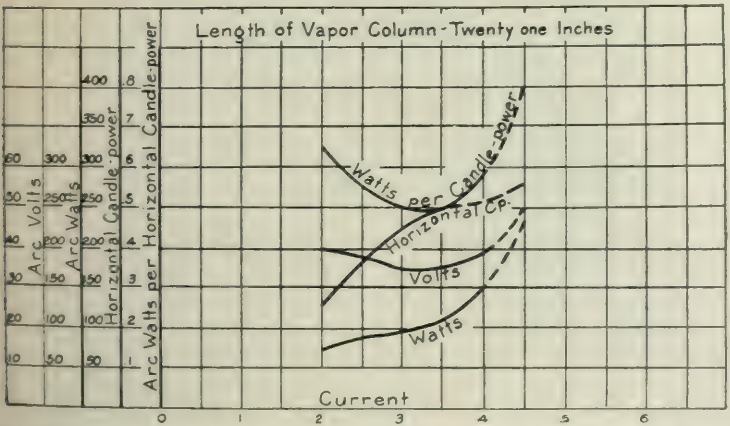


Fig. 14.—Curve showing maximum efficiency of a 21-inch, 3.5-amp., 110-volt, direct-current, tilting-type, mercury-vapor lamp.

Von Recklinhausen reported a decrease of 20 per cent. during the first 100 hours. Tests of the newer types of mercury-vapor lamps made for the author did not indicate as great a decrease at the beginning. A test of an alternating current tube, however, showed a decrease of 41 per cent. in 1339 hours. Also

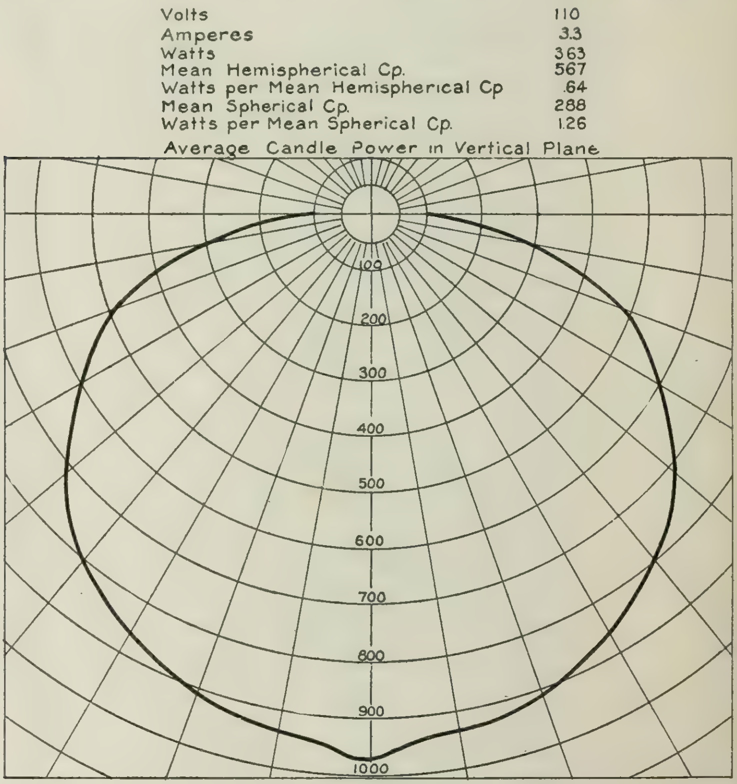


Fig. 15.—Distribution curve of a 21-inch, 3.3-amp., 110-volt, direct-current, automatic, mercury-vapor lamp.

a test on a 45-inch direct-current multiple tube showed a candle-power decrease of 46 per cent. in 839 hours (fig. 10).

Arc Lamps—Some illuminants because of their peculiar fitness for a particular form of illumination cannot be justly compared with others. The luminous arc lamp, for example, is a very efficient illuminant for street lighting, but for other illumination it might be inefficient. A recent test to ascertain

DATA ON ARC LAMPS.

	Miniature carbon 110 volts 4 amp D C	Standard multiple carbon 110 volts 5 amp. D C.	Standard multiple carbon 110 volts 6½ amp D C.	Intensified arc 110 volts 5 amp D C.	Standard multiple carbon 110 volts 6 amp. 60 cycle A C.	Standard multiple carbon 110 volts 7½ amp 60 cycle A C.	Twin carbon multiple 220 volts 3½ amp. D. C.
Type of lamp	Miniature carbon	Standard multiple carbon	Standard multiple carbon	Intensified arc	Standard multiple carbon	Standard multiple carbon	Twin carbon multiple
Voltage at terminal	110 volts	110 volts	110 volts	110 volts	110 volts	110 volts	220 volts
Voltage at arc	83 volts	80 volts	80 volts	80 volts	72 volts	72 volts	2 arcs each 80 volts
Current	4 amp. D C	5 amp. D. C	6½ amp. D. C	5 amp D. C.	6 amp. 60 cycle A. C.	7½ amp. 60 cycle A. C.	3½ amp. D. C.
Watts	451	550	715	550	430	540	715
Power factor					65.5	65.5	
Reflectors and glassware	White porcelain reflector, opal inner, no outer globe	Porcelain reflectors, light, opal inner, no outer globe	Porcelain reflectors, light, opal inner, no outer globe	Porcelain reflector, opal inner, no outer globe	Porcelain reflector, opal inner, no outer globe	Porcelain reflector, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe
Electrodes	½" carbon	½" carbon	½" carbon	Two ½" upper ⅜" lower carbons	⅝" carbon	½" carbon	(2 pair) ½" carbon
Life of electrodes	50 hours	150 hours	100 hours	75 hours	125 hours	100 hours	150 hours
Maximum C. P.	440 at 60 degrees below horizontal	400 at 30 degrees below horizontal	580 at 30 degrees below horizontal	600 at 55 degrees below horizontal	230 at 30 degrees below horizontal	310 at 30 degrees below horizontal	280 at 30 degrees below horizontal
Mean spherical, C. P.	218	215	318	225	160	215	195
Watts per M. S. C. P.	2.06	2.56	2.25	2.44	2.68	2.51	3.7
Mean hemispherical C. P.	332	379	559	414	270	371	240
Watts per M. H. S. C. P.	1.36	1.45	1.28	1.33	1.56	1.45	3.05

	Standard carbon 220 volts 3½ amp. D C	Series D C open carbon arc 50 volts 6.6 amp	Series D C open carbon arc 50 volts [illegible] amp	Series D C enclosed carbon arc [illegible] volts [illegible] amp	Series A C [illegible] amp	Series A C [illegible]
Type of lamp	Standard carbon	Series D. C. open carbon arc	Series D. C. open carbon arc	Series enclosed carbon arc	[illegible]	[illegible]
Voltage at terminal	220 volts	50 volts	50 volts	[illegible] volts	[illegible]	[illegible]
Voltage at arc	150 volts	45 volts	45 volts	[illegible] volts	[illegible]	[illegible]
Current	3½ amp. D. C.	6.6 amp.	9.6 amp.	[illegible] amp.	[illegible] amp.	[illegible]
Watts	715	330	480	[illegible]	[illegible]	[illegible]
Power factor					[illegible]	[illegible]
Reflectors and glassware	Porcelain reflectors, light opal inner, no outer globe	Clear outer	Clear outer	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled [illegible] clear inner and outer globes	[illegible]
Electrodes	½" carbon	½" carbon (2 pair)	½" carbon (2 pair)	½" carbon	[illegible]	[illegible]
Life of electrodes	150 hours	18 hours	18 hours	125 hours	[illegible]	[illegible]
Maximum C. P.	240 at 30 degrees below horizontal	720 at 45 degrees below horizontal	1285 at 45 degrees below horizontal	530 at [illegible] degrees below horizontal	[illegible]	[illegible]
Mean spherical, C. P.	160	265	400	[illegible]	[illegible]	[illegible]
Watts per M. S. C. P.	4.44	1.25	1.02	[illegible]	[illegible]	[illegible]
Mean hemispherical C. P.	215	395	690	[illegible]	[illegible]	[illegible]
Watts per M. H. S. C. P.	3.43	.82	0.71	[illegible]	[illegible]	[illegible]

DATA ON ARC LAMPS.

Standard arc [illegible]	Series D. C. open carbon arc [illegible] volts [illegible] amp.	Series D. C. open carbon arc [illegible] volts [illegible] amp.	Series D. C. enclosed carbon arc 75 volts 6.6 amp.	Series A. C. enclosed carbon 72 volts 6.6 amp.	Series A. C. enclosed carbon 77 volts 7½ amp. 60 cycles	Flaming arc 55 volts 12 amp. D. C.	Flaming arc 55 volts 12 amp. A. C. 60 cycles	Multiple vertical carbon flame arc 110 v. 6.5 amp. D. C.	Multiple flame 110 volts 5.5 amp. D. C.	Multiple flame 110 volts 7 amp. A. C. 60 cycles	Series vertical carbon flame arc 75 volts 6.6 amp. D. C.	Series flaming arc 50 volts 12 amp. A. C. 60 cycles	Series luminous arc 78 volts 4 amp. D. C.	Series luminous arc 75 volts 6.6 amp. D. C.	Multiple luminous arc 110 volts 6.5 amp. D. C.
[illegible] carbon	Series D. C. open carbon arc	Series D. C. open carbon arc	Series enclosed carbon arc	Series A. C. enclosed carbon	Series enclosed carbon	Flaming arc	Flaming arc	Multiple vertical carbon flame	Multiple flame	Multiple flame	Series vertical flame arc	Series flaming arc	Series luminous arc	Series luminous arc	Multiple luminous arc
[illegible] volts	[illegible] volts	50 volts	75 volts	77 volts	77 volts	55 volts	55 volts	110 volts	110 volts	110 volts	78 volts	50 volts	78 volts	78 volts	110 volts
[illegible] volts	45 volts	45 volts	73 volts	72 volts	72 volts	45 volts	45 volts	75 volts	70 volts	70 volts	75 volts	45 volts	75 volts	75 volts	75 volts
[illegible] amp. D. C.	[illegible] amp.	6.6 amp.	6.6 amp.	6.6 amp.	7½ amp. A. C. 60 cycles	12 amp.	12 amp.	6.5 amp.	5.5 amp. D. C.	7 amp. A. C. 60 cycles	6.5. amp. D. C.	12 amp.	4 amp. D. C	6.6 amp. D. C.	6.5 amp. D. C
[illegible]	[illegible]	480	495	425	480	660	500	715	605	525	510	440	310	510	[illegible]
				(Lamps only) 84 %	(Lamps only) 84 %		75 %			68 %		75 %			
[illegible]	Clear outer	Clear outer	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled iron reflector clear inner and outer globes	Light opal globe	Light opal globe	40" inverted diffuser alba globe	Clear inner, opal outer porcelain enameled reflector	Porcelain enameled reflector, clear inner, opal outer globe	26" inverted diffuser alba globe	Opal outer	Clear outer	Clear outer	Clear globe
[illegible] carbon	[illegible] carbon [illegible] pair	[illegible] carbon [illegible] pair	½" carbon	½" carbon	½" carbon	Yellow ⅜"	Yellow ⅜"	Upper ½" carbon, lower only mineralized	⅝" upper carbon ⅞" miner. lower	⅝" upper carbon ⅞" miner lower	Upper ⅜" carbon lower only min	Yellow	Upper copper slag lower ½" magnetite	Upper copper slab lower [illegible] magnetite	Upper copper slab lower [illegible] magnetite
[illegible] hours	[illegible] hours	[illegible] hours	125 hours	125 hours	100 hours	17 hours	17 hours	20 hours	60 hours	50 hours	20 hours	12 hours	175 hours	125 hours	50 hours
[illegible] degrees below horizontal	[illegible] degrees below horizontal	[illegible] at [illegible] degrees below horizontal	530 at 30 degrees below horizontal	250 at 20 degrees below horizontal	305 at 20 degrees below horizontal	2150 at 90 degrees below horizontal	1350 at 90 degrees below horizontal	2425 at 30 degrees below horizontal	1500 at 30 degrees below horizontal	1250 at 30 degrees below horizontal	2350 at 30 degrees below horizontal	1350 at 90 degrees below horizontal	700 at 10 degrees below horizontal	[illegible] at 10 degrees below horizontal	[illegible] at [illegible] degrees below horizontal
[illegible]	[illegible]	[illegible]	240	144	173	1460	8.5	1129	700	583	1223	875	285	720	720
[illegible]	[illegible]	[illegible]	1.71	2.95	2.77	0.45	0.52	0.63	0.80	0.90	0.42	0.50	112	0.71	[illegible]
[illegible]	[illegible]	[illegible]	479	232	291	[illegible]	1170	2058	1210	875	2051	1170	545	1340	[illegible]
[illegible]	[illegible]	[illegible]	1.03	1.83	1.65	0.32	0.39	0.35	0.50	0.60	0.25	0.37	0.50	0.38	0.53

the average life candle-power of a 6.6-amp. direct-current series lamp of this type showed that during 109 hours there was a decrease of 17.2 per cent. in the candle-power. The life of the electrodes was 130 hours.

A typical life candle-power curve[1] of an ordinary carbon arc lamp is shown in fig. 16. It will be noted from this curve that

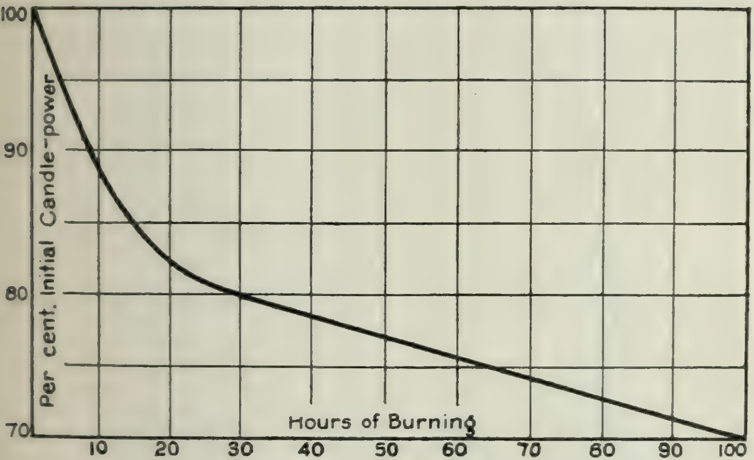


Fig. 16.—Mean life candle-power curve of a standard arc enclosed lamp.

the candle-power fell to 70 per cent. of the initial candle-power at the end of 100 hours, and that the average candle-power performance was 78 per cent.

As a conclusion to this paper the author has summarized the foregoing notes on illuminants in a table given below. An

Illuminant	Per cent. of initial candle-power (Average)
Gas mantle (high grade)	70
Mercury vapor lamp, alternating-current	75
Mercury-vapor lamp, direct-current	61
Enclosed carbon are lamp	78
Magnetite arc (6.6-amp.) lamp	90
Drawn-wire tungsten filament incandescent lamp (1,000 hours) 60- and 100-watt, 100-volt—(efficiency 1.18 w.c.p.)	94

average life candle-power value has been assigned for each of the illuminants. The author considers these values fairly representative of the types of illuminants mentioned.

[1] *Stand. Hndbk.*, Sec. 12, p. 267.

DISCUSSION.

Dr. A. S. McAllister (Communicated) :—The author mentions a method for determining the mean spherical candle-power of a mercury-vapor lamp by means of observations made in three planes. Unless used with extreme caution, this method might lead to very incorrect results in that it represents a generalization from too limited a number of observations of quantities that vary widely in magnitude. However, his assumption that the total number of lumens measurable on any surface completely surrounding the tube is constant independent of the distance between the tube and the surrounding surface, is absolutely

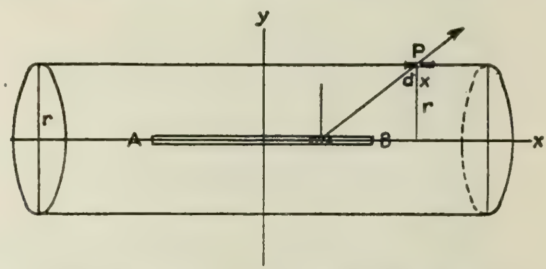


Fig. 17.—Partial perspective view of cylindrical area illuminated by a "surface line" source.

accurate, certain other writers to the contrary nothwithstanding.[1]

When a light tube is placed within a cylinder of finite length as shown in Fig. 17, it is at once evident that in order to ascertain the total flux produced by the luminous tube, it is necessary to integrate the flux density not only over the inner surface of the cylinder, but also over the two circular ends. When this is done it is found that each element of the light line produces an absolutely constant amount of total flux over the surface of the envelope independent in all respects of the size of the envelope and of its position therein. Incorrect transformations of unnecessarily complicated equations for representing the very simple photometric relations involved, and abortive attempts to interpret the equations thereby evolved, have led certain investigators to announce that the laws that apply to the total flux from a point source are not applicable to a line source; that

[1] See *Trans. Ill. Eng. Soc.*, pp. 318, 321, 331 and 363, April, 1911.

is, that the summation of the flux density over all areas lighted by a surface line source does not physically represent the real flux of light, and differs therefrom numerically according to the shape and size of the illuminated area. Such a statement is contrary to the well-established law of conservation.

It seems proper to show in how simple a manner the constancy of the total measurable flux from a luminous tube can be proved for the special arrangement indicated in partial perspective in Fig. 17 and shown more in detail in Fig. 18.

The luminous mercury-vapor path is a "volume source" of light, but the lamp as actually constructed, with the luminous

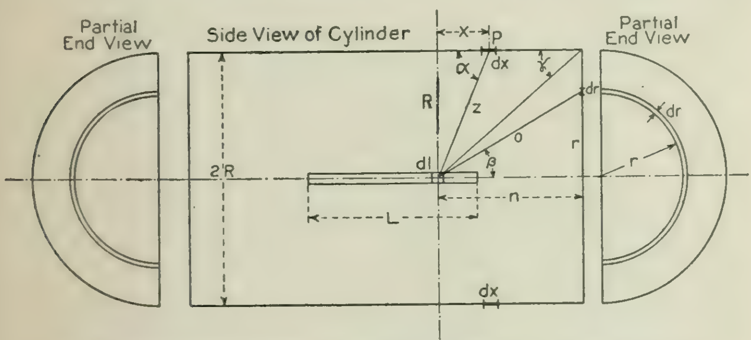


Fig. 18.—Dimensional diagram of photometric relations of a cylindrical area illuminated by a "surface line."

path within a glass enclosure having opaque ends, can most accurately and conveniently be treated as a "surface-line" source; that is, as a source to which the cosine law is applicable. Assume, therefore, that the "surface-line" source in Fig. 18 has an apparent candle-power observed radially of c per unit length. An elementary length dl would produce at the point P on the inner surface of the cylinder a flux density of $(cdl)\sin^2\alpha \div z^2$, and the total flux over the elementary area $2\pi R dx$ would be

$$d\psi_c = 2\pi R dx (cdl) \sin^2\alpha \div z^2 \qquad (1)$$

Now $x = R\cot\alpha$,

$$dx = R d\alpha \div \sin^2\alpha,$$

$$z = R \div \sin\alpha.$$

Hence

$$d\psi_c = 2\pi(cdl)\sin^2\alpha\, d\alpha \qquad (2)$$

The whole flux produced by the line element (dl) over the cylindrical area subtended by the angle γ is

$$\psi_c = 2\pi\,(cdl) \int_{\gamma}^{\frac{\pi}{2}} \sin^2 a \; da = 2\pi\,(cdl) \Big[\tfrac{1}{2}\,(a - \sin a \;\cos a) \Big]_{\gamma}^{\frac{\pi}{2}}$$

$$= \pi(cdl)\left[\frac{\pi}{2} - \gamma + \sin\gamma\cos\gamma\right] \ldots\ldots\ldots\ldots (3)$$

Consider now the flux produced by the line element (dl) on the right-hand circular end, taking first the ring having an area of $2\pi rdr$.

$$d\psi_e = 2\pi rdr(cdl)\sin\beta\cos\beta \div o^2 \ldots\ldots\ldots\ldots (4)$$

$$o = n \div \cos\beta,$$

$$r = n\tan\beta,$$

$$dr = nd\beta \div \cos^2\beta,$$

$$d\psi_e = 2\pi n \frac{\sin\beta}{\cos\beta}\frac{nd\beta}{\cos^2\beta}(cdl)\sin\beta\cos\beta\frac{\cos^2\beta}{n^2}$$

$$= 2\pi(cdl)\sin^2\beta d\beta \ldots\ldots\ldots\ldots (5)$$

For a circular end with radius of R, the angle β becomes γ and the total flux for this angle is

$$\psi_e = 2\pi(cdl)\int_{0}^{\gamma}\sin^2\beta d\beta = 2\pi(cdl)\Big[\tfrac{1}{2}(\beta - \sin\beta\cos\beta)\Big]_{0}^{\gamma}$$

$$= \pi\,(cdl)\Big[\gamma - \sin\gamma\cos\gamma \ldots\ldots\ldots\ldots (6)$$

To find the total flux over the right-hand part of the cylinder and the right-hand end, equations (6) and (3) must be added. Hence

$$\psi_c + \psi_e = \frac{\pi^2}{2}\,(cdl) \ldots\ldots\ldots\ldots (7)$$

It is to be noted that this value is independent absolutely of the angle γ, the length n and the radius R, hence an exactly equal value would be obtained for the flux produced along the left-hand inner surface of the cylinder and the circular area at

the end, so that the total flux produced by the elementary light line (dl) is $\pi^2(cdl)$. For the whole light line L the total flux is evidently $\pi^2 c$L.

Contrary to the conclusions that have been derived from much more complicated analyses of this problem, the value for the measurable total flux is independent of the diameter of the enclosing cylinder or of its length, as must inevitably follow from the law of conservation to which scientists have as yet been unable to discover any exceptions.

Dr. J. C. Pole (Communicated) :—I was surprised to learn that the formulæ contained in my paper on "Photometry of Mercury-Vapor Lamps," recently presented to the society, were "empirical." My equations were based on exact mathematical computations and do not contain anything which may justly be called empirical. I was also interested to learn "that it is difficult to give physical conceptions to the various component parts of the equations." The "physical component parts" of my equations are length and light intensity, which conceptions are certainly exactly defined. I have also noted that "the equations are unintelligible for the ordinary layman who is expected to use them." I should say it would be very odd to expect the ordinary layman to use integral equations in figuring the candle-power of a lamp.

As is shown very clearly in my paper and proved by different scientists, it is more than questionable if it is, according to Mr. Ashe, "preferable to lean toward the old method of integrating the total flux in which the mercury-vapor tube is considered as a point light source."

Mr. Ashe states further that "when mercury-vapor tubes are photometered at a distance of twenty feet, this eliminates errors from considering the tube as a punctiform source of light." In other words, if the mercury-vapor tube were 5 inches or 100 inches long it would make no difference.

I was also curious to learn that "errors due to the Purkinje effect are eliminated at this photometer distance (20 feet), provided that the average mean spherical candle-power is determined in three planes and the final average taken." Mr. Ashe's conception of the Purkinje effect is evidentally at variance with

mine at least. Notwithstanding the latter-mentioned statement Mr. Ashe has taken the curves of light distribution in one plane only and so computated the total flux of light. It is more usually conceded by those who have done photometric work, however, that it not admissible to figure the total flux of light of a long mercury-vapor tube from one curve of light distribution only, as the photometric body of the mercury-vapor lamp, especially with reflectors, never can be assumed as a body of rotation. An approximatively correct method of figuring the luminous flux of the mercury-vapor lamps from curves of light distribution, provided these curves are taken at a photometer distance of at least ten times the length of the luminous tube, is the following:—

Let T_{pa} signify the light intensity parallel to the axis of the luminous tube under the latitude a (*i. e.*, counting the angle from the tube axis); let T_{na} be the light intensity normal to the tube axis under the same latitude. Then the luminous flux is approximately

$$\Delta\phi_a = 2\pi\sqrt{T_{pa}T_{na}} \, . \cos a \, . \Delta a,$$

and the mean hemispherical light intensity

$$T = \sum_{a=0}^{a=\frac{\pi}{2}} \sqrt{T_{pa} \, . \, T_{na}} \cos a \, \Delta a.$$

It seems strange to me that Mr. Ashe, figuring the total flux of mercury-vapor lamps as he does, should arrive at results which are very close, indeed, to the correct figures for these lamps. Mr. Ashe adds, as if by way of qualification, that "the tests were made in a well equipped engineering laboratory and although only one tube was tested in each instance, the results, as far as scientific accuracy is concerned, were the best obtainable." My experience has been that scientific accuracy does not depend so much upon the good equipment of the laboratory as upon the ability and the conscientiousness of the investigator.

Fig. 13 of Mr. Ashe's paper represents "a test of a 3.3-ampere tilting tube." The real tilting tube on the market is a 3.5-ampere tube. Nevertheless the readings were taken at the abnormal current of 3.3-amperes which, as I have proved by exact in-

vestigations in above quoted paper, gives a poorer efficiency for the lamp than the normal current of 3.5 amperes.

Mr. Ashe exhibits other curves showing the falling off of the candle-power with the age of mercury-vapor lamps. In each instance he measured only one tube. Readings of the lamp current and the voltage between the tube terminals, as would be proper, are not given. In one instance (Fig. 8) he finds the average performance with 60.9 per cent. in the other case (Fig. 9) with 73.9 per cent. of the initial candle-power. In the first case it was a direct-current non-automatic tube; in the other case an alternating-current automatic lamp. As the alternating-current lamp operates on the principle of the rectifier and the direct-current in the lamp tube is in both cases the same, namely 3.5 amperes, and as the depreciation in candle-power depends largely on the current under which the tube operates, the above-mentioned curves are but of little value for drawing conclusions. Furthermore, these two curves (Figs. 8 and 9) differ considerably in shape and character. My long experience with these types of lamps has been that this can not be so.

Mr. Ashe (Communicated in reply):—It is realized, as Dr. McAllister points out in discussing this paper, that the conclusions of Dr. Pole's paper, which I referred to in my paper under *Mercury-vapor Lamps,* could be deduced in a much simpler manner, and in such form that the ordinary photometrist would have no difficulty in interpreting them. I still believe that any photometrist attempting to use Dr. Pole's equations would find them unwieldy. Any one who has ever had the ordinary college course in differential and integral calculus, and also differential equations, would find little difficulty with Dr. Pole's paper. Some people enjoy the mental gymnastics which come from playing with the higher mathematics. To me, however, mathematics is only a useful means for arriving at a definite conclusion, and where this conclusion can be arrived at by simple experimental means, I prefer the latter course.

Dr. Pole takes advantage of a slight looseness of the text in which he comments on photometering a mercury-vapor lamp at twenty feet. It is well known, as Dr. Hyde has pointed out,

that photometering a tube at a distance equal to five times the length of the tube, is sufficient, as the error at this point is practically negligible. With commercial tubes, such as mentioned in the paper, this distance is equal to about twenty feet. Dr. Pole feels perhaps that a distance equal to ten times the length of the tube is more accurate? It is, to a certain extent. On the other hand at this distance, the illumination on the photometer screen is less than a foot-candle when photometering a lamp with a reflector at some of the smaller angles, at which points it is extremely difficult to make comparison between like-colored illuminants let alone different colored illuminants. Furthermore at these low illuminations, the error from the Purkinje effect is at least from 15 to 25 per cent., as I know from measurements made. It is interesting to note that Dr. Pole acknowledges that there is a depreciation in candle-power of the mercury-vapor tube; that he has made a study of this depreciation, and that the depreciation depends almost entirely upon the current at which the lamp operates. I inferred from Mr. Evans' discussion that there was very little depreciation. I am sorry that Dr. Pole likewise gives no values as to what he has found to be the average candle-power performances of the lamp.

Mr. W. A. D. Evans:—I have read with a great deal of interest Mr. Ashe's paper and must say that he is to be congratulated for the data which he has collected regarding different types of illuminants. I am particularly interested in the data which he has collected on the mercury-vapor lamps, and would say that in looking over his figures and curves, I find that in most cases, they not only agree with the manufacturer's figures but in some cases are even better.

There are, however, one or two points which I would like to criticise. In the first place the measurements of candle-power as shown in Figs. 13 and 15, I note are made on a mercury-vapor lamp operated at 3.3 amperes; and as shown by the curve in Fig. 14, the most efficient point of that lamp for both these types is 3.5 amperes, at which point all lamps are rated by the manufacturers, and it is the point at which lamps are recommended to be operated.

As far as I can observe from the curve in Fig. 14, the horizontal candle-power at 3.3 is about 235, whereas at 3.5 it is 250, or a difference of 15 candle-power, approximately an increase of 6.5 per cent. Therefore, while he figures the mean spherical candle-power at 3.3 to be 182, at 3.5 amperes it should be increased approximately 12 candles, making a total of 194 mean spherical candle-power for the tube.

I note on curve as shown in Fig. 11 that the mean horizontal candle-power of the 45 in. tube is figured as being 754. The Cooper-Hewitt Electric Company claim for this type of lamp 700 candle-power. In curve, Fig. 12, the mean horizontal candle-power is figured at 888, while the manufacturers' rating on this lamp is 800. In Fig. 15, the mean horizontal candle-power at 3.3 amperes is 567 and at 3.5 amperes this would be 604; whereas the rated candle-power by the manufacturer is 600. Mr. Ashe's figures therefore check excellently with the results obtained by the manufacturer.

I note that Mr. Ashe quotes a statement by Prof. Freudenberger of Delaware College and Dr. Von Recklinghausen in regard to the rapid falling off in the candle-power of the tube. In this connection, I might state that the tubes referred to by both gentlemen were made over seven years ago and since that time considerable improvement in the manufacture of mercury-vapor lamps has been made.

Mr. Ashe's tests on the depreciation of candle-power are simply made on one lamp of each type. I do not think that a fair average value can be drawn from such limited tests. A test of one tungsten lamp could not be taken as a basis for candle-power depreciation throughout life for that type of lamp.

I also note that he states that there is a greater depreciation of the candle-power of the direct-current non-automatic lamp than the automatic alternating-current lamp. There is no apparent reason why one should differ from the other, inasmuch as both lamps in their construction are practically the same.

I would like to ask Mr. Ashe if he made any measurements on the tube diameter, and also if the direct-current (that is the current through the tubes) on both types of lamps was kept con-

stant at 3.5 amperes in each case, and if the dust on the reflectors and tubes was occasionally wiped off, or if this was allowed to accumulate throughout the test.

I note that according to Fig. 12, that the distribution curve on the alternating-current lamp was taken at 7 amperes, while the candle-power depreciation curve was taken at 7.1 amperes.

While Mr. Ashe's figures show a falling off in the candle-power, they are derived from a test of only one lamp and I might state that my experience has been that I have never found that the decrease in the candle-power is sufficient to cause a customer to purchase a new lamp. There has never been found, up to the present time the necessity of determining a "smashing point" for the mercury-vapor lamps and there are lamps in service which were installed seven years ago. I know of lamps that have been in commercial service for 56,000 burning hours. Some of these lamps are still operating.

In regard to the depreciation in candle-power, I might state that the initial candle-power quoted by the manufacturers of the mercury-vapor lamp is not as high as the actual candle-power derived from the lamp. This will be apparent, as I have shown above that Mr. Ashe's figures for candle-power are higher than those quoted by the manufacturers. Therefore, the falling off from the rated candle-power is not as marked in this lamp as Mr. Ashe's figures tend to show.

As is well known, the mercury-vapor lamp does not depend upon its candle-power alone for its reputation, but its main claim is upon its visual acuity, and as stated by Dr. Bell in a recent article in the *Electrical World,* he found that the acuity of this lamp at normal intensities was practically one and a half to two times that of the incandescent lamp, due to the spectrum of the lamp being almost monochromatic at the most efficient point.

Mr. Ashe (Communicated in reply) :—Commenting on Mr. Evans' discussion it is interesting to note that the distribution curves of mercury-vapor lamps given in the paper, check up closely with the manufacturers values of similar tubes, although the tests were made only on single tubes.

Regarding the candle-power life performance, Figs. 8, 10 and 11 represent tests on the same lamp, and likewise Figs. 9 and 12 represent tests on the same lamp.

Although the values of light distribution of these lamps seem to check so well with Mr. Evans' values, and to indicate good lamps, still he states that the candle-power life values as given do not check with values which they have for other lamps, but as Mr. Evans does not give any candle-power life performance for the lamps made by his company, it is impossible to arrive at any values of depreciation of candle-power other than those given in the paper. I am aware, however, of other tests that have been made which show a heavy depreciation, although I am not at liberty to give out the results of these tests.

Regarding Mr. Evans' statement that 6.5 per cent. should be allowed according to Fig. 14 for the difference in candle-power of the lamp when operating at 3.5 amperes instead of 3.3 amperes, I would state that if Mr. Evans will look at the curve in Fig. 14 closely he will note that, although the lines are drawn rather heavily, the candle-power correction which is given in the table is quite conservative and represents about the correcting factor which should be used. Mr. Evans, however, is undoubtedly in a position to tell more exactly what that factor is, and I am sorry he did not state what he felt it should be in preference to attempting to deduce the values from the curves given. If Mr. Evans will refer to the curve in Fig. 10, he will find that about the same factor as has been used in the paper would apply.

Mr. Evans also states that it is not fair to arrive at a depreciation factor from tests of single lamps. If the mercury-vapor lamp were constructed similar to an incandescent lamp where there is a possibility of large variation of manufacture arising it might be stated that this claim is fair. As the device is so simple, however, consisting of nothing but a tube, a vacuum and a given amount of mercury, it would seem that so long as the mercury was reasonably pure and that the vacuum was exhausted in each case to the same extent, that there should be very little variation in candle-power performance of the tubes.

Mr. Evans intimates that owing to the long life which they obtain from mercury-vapor lamps and the fairly high candle-power performance, that there is no such thing as a smashing point for a mercury-vapor lamp. If the curves of Figs. 8 and 9, given in the paper, represent approximately average conditions and Mr. Evans has given no data to the contrary, in Fig. 8 where the candle-power falls to 55 per cent. of initial candle-power in 600 hours, it would seem that the lamps decidedly have a smashing point.

Mr. Evans offers the further argument that owing to the difference in the initial candle-power, which is given in the paper, from the values which are being obtained for lamps, that the falling off in candle-power is not so great as my figures tend to show. As the curves are figured in per cent. of initial candle-power throughout life, it does not seem that this argument applies.

Another statement made by Mr. Evans is that in a recent article by Louis Bell in the *Electrical World* it was shown that the mercury-vapor lamp had a higher acuity value than that of a tungsten lamp. I have had occasion to make a number of tests on the subject of acuity, some of which have been published from time to time in the various technical journals. Upon reference to the tests by Dr. Bell, by Alexander Dow, by the author and others, it will be noted that the values have all been obtained for low intensities of light. Recently some tests were conducted for me in which intensities of light on the test were high, extending from 200 foot-candles down to 3 foot-candles. The results of that test which was made by two men are shown in the following diagram, Fig. 19. It will be noted that for high intensities the tungsten lamp gives a higher acuity than the mercury-vapor lamp, and for intensities of about three foot-candles there seems to be practically little difference in the acuity of both these illuminants.

Incidentally, the latter mentioned tests were made in a darkened room; the lamps were operated from a storage battery, and were burned for a reasonable time to allow the current consumption to become steady. The eye was used for distant vision.

Concerning Dr. Bell's results, it should be noted that the test

results which he published were for "near vision," which condition hardly applies to ordinary shop practice.

It might be interesting at this point to give a theory as to the cause of the decrease in candle-power of a mercury-vapor lamp. It is fair to assume that if the tube contains a certain percentage of oxygen, no matter how well the vacuum is exhausted, this oxygen tends to oxidize the mercury in the tube when the tube is in operation. Consequently a thin film forms on the inner surface of the tube, which decreases the candle-power performance. If the vacuum is very good and the tubes contain only a very small percentage of oxygen, the drop in

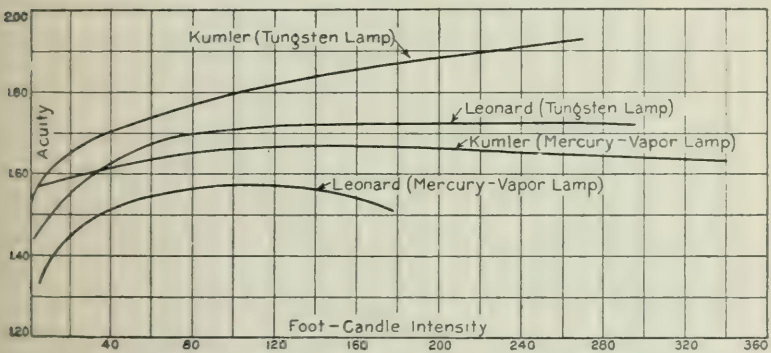


Fig. 19.—Acuity measurements at high intensities, distant vision for tungsten and mercury-vapor lamps.

candle-power would be rapid, and then the candle-power would remain quite constant. This is indicated in the statement made by Von Recklinhausen, in the *Elektrotechnische Zeitschrift*, December 22, 1904, where it is said that the candle-power decreased 20 per cent. during the first hundred hours and then remained constant. It will also be noted in the curves of Figs. 8 and 9, that the candle-power tends to become constant after about 1,000 hours. If a medium vacuum were obtained, the curves would naturally fall off gradually. These are probably the conditions indicated in the tests, Figs. 8 and 9, where not the best possible vacuum that could be obtained was probably used. These statements are offered simply as a possible explanation as to why it would be impossible to obtain a peak in the candle-power life curve of a mercury-vapor lamp, also to show why the candle-power would

decrease during the unstable period, and why it would tend to remain constant beyond that point. These comments, however, are simply my own theory and may not represent the actual facts.

Mr. P. S. Millar:—The first part of this paper enters upon the discussion of the proper basis for comparison of illuminants. I think there is no question but that the total flux of light is the only possible basis of comparison of illuminants when the illuminants are considered as light producers. Suggestions which have been put forward for other bases of rating, have grown out of considerations of illuminating effectiveness. Incidentally, I have noted with interest that most such suggestions have been put forward by manufacturers of lamps or lighting devices, and it happens that the particular form of rating advocated by the manufacturer or his agent has been calculated usually to benefit the lamp which he is most interested in exploiting. I mention this not to be cynical, but merely to suggest that any departure from the total flux in rating illuminants involves the possibility of commercial complications which are not met in dealing strictly with total flux measurements. Experience with other bases of rating has been unfortunate in the past, and I think should be a warning.

Nevertheless there are differences which cannot be ignored in illuminating effectiveness of illuminants having the same total flux of light, and the only way it seems to me, to solve this question is to arrive at some general term of total flux of each illuminant, as a light producer, and then arrive at co-efficients of utilization of each illuminant for each specific class of illuminating service. Such co-efficients of utilization when published, would have to be hedged about by many restrictions to prevent improper use by the many incompetent people who might use the figures.

The paper suggests that a fair basis of comparison is the average candle-power throughout commercial life. I think that may be accepted as correct. The only question is as to its practicability. To begin with, the commercial life must be agreed upon. As an example of the difficulty here involved, it may be noted that Mr. Ashe seems undecided whether 2,000 or 1,000 hours should be given for tungsten lamps.

After discussing in this manner the basis for rating illuminants the paper proceeds to give data on illuminants, gas illuminants first. If I am correct, the author has based his conclusions as to candle-power maintenance of gas lamps, upon gas and gasoline street lamps under service conditions. He compares these with tungsten lamp performances in the laboratory. I do not think that is quite fair.

Regarding arc lamps this paper presents considerable information of such importance that I am impelled to ask the authority for these data. I take it that Mr. Ashe did not make the tests, for if he had I doubt that he would have published the results without further qualification.

I have not had such opportunity as I should have liked to go over these data, but I have glimpsed among them some figures which seem to be typical. There are other figures I could not endorse. Incidentally I note for the 6.8-ampere 78-volt flaming arc lamp, which is the so-called Boston type, a watt per mean candle-power value of 42/100ths. For this same lamp Mr. W. D'A. Ryan at the National Electric Light Association convention, last year gave 28/100ths watt per candle-power. The fact that these values differ by 40 per cent. illustrates the danger of publishing such data in this form.

Finally, I should like Mr. Ashe to mention the authority for the tests, the number of samples in each case, and other data necessary to enable one to judge how typical and reliable these various figures are.

Mr. Ashe (Communicated in reply) :—It is interesting to note, after the various comments in Mr. Millar's discussion about the presentation of data, the attitude of manufacturers presenting such data and other unfortunate experiences with the rating of lamps in the past, that he agrees with the fundamental basis of comparison which I recommend, namely, comparisons should be made on the average candle-power performance throughout life. In this connection Mr. Millar also mentions the difficulty of deciding upon the life of various illuminants, and while I did not follow this practice entirely throughout the paper, it would seem that the proper life to take would be that of the guaranteed life of the device by the manufacturer; for example, in the case of the improved tungsten lamp this would be 1,000 hours,

which figure I used in my paper, although the results of the tests given in Figs. 1 and 2, show a life of 1,900 and 2,000 hours. It would have been a comparatively easy matter to cut off these curves at 1,000 hours, which I was tempted to do in preparing the paper, but I thought that as the curves represent actual tests which were made, that it would be but fair to print the values as found similar to the one which has been given for the mercury-vapor lamps. If, however, the practice of using the guaranteed life had been used with the mercury-vapor lamps, the average candle-power performance would have been still lower than those given in the paper. But as these tests had not been continued beyond the period given in the paper, it was felt that it would be preferable to take the values from the number of hours which the lamps had burned, which have been indicated in the diagrams. It would seem, however, that as an ultimate basis of comparison the guaranteed life of the device should be the one on which the average candle-power performance should be figured.

Mr. Millar requests the authority for the data which have been presented. Figs. 1 and 2 of incandescent lamps were made by Mr. Deshler in the Harrison laboratory of the General Electric Co. Figs. 4, 5, 6 and 7 represent tests I made personally assisted by Mr. Powell and Mr. Perkins in the laboratory at Harrison on Harrison gas. Figs. 8 to 15 inclusive, were tests made in the laboratory of the General Electric Company in Schenectady, N. Y. Most of the tests were made under the personal supervision of Mr. S. L. E. Rose, an assistant of Mr. W. D'A. Ryan who is in charge of the laboratory. Fig. 16 was taken by averaging the two curves in the Standard Handbook which represents values obtained by Dr. Matthews. The majority of the arc lamp tests were also made by Mr. Rose and represent the average value of a large number of lamps and a large number of readings at each point. A few of the figures given for lamp A and lamp R were taken from lamps of other manufacturers. The majority of the figures represent tests on General Electric Company lamps. The few remaining figures check within 10 per cent. of the standard values of other lamps. These data are referred to more in detail in Mr. Rose's discussion.

Mr. S. L. E. Rose:—There has been so much adverse criticism to

the data which Mr. Ashe has given that it must be gratifying to him to find that at least some of his figures and curves on the mercury-vapor lamp agree very closely with those obtained by others. All the curves on the mercury-vapor lamp given in Mr. Ashe's paper are results of tests made at the illuminating engineering laboratory of the General Electric Company and agree almost exactly with those given by Mr. Evans here to-night. Mr. Evans takes exception to curve shown in Fig. 15, stating that this lamp should have been operated at 3.5 amperes instead of 3.3. In answer to this I would say that only one lamp of this type was tested and when connected and adjusted according to instructions sent with it, it took 3.3 amperes. I know of one other lamp of this type which operates at the same current as the one which was tested. The manufacturers claim 600 mean hemispherical candle-power for this lamp when taking 385 watts at the terminals. This would give an efficiency of 0.64 watts per mean hemispherical candle-power, the same as given in Fig. 15.

Figs. 9 and 12 show the results of tests made on the 7.1 ampere alternating-current multiple mercury-vapor lamp. The candle-power obtained from the distribution curve (Fig. 12) was used as the initial value for the depreciation test shown in Fig. 9, and at the bottom of Fig. 12 it should be stated that this is a 7.1-ampere lamp, the same as in Fig. 9, which gives the rating. Mr. Evans states that the depreciation curves do not agree with those obtained by him. The difference may be accounted for by the methods used in making the tests. He made the current in the tubes constant throughout his tests while the tests set forth in the paper were made with a constant potential held at the lamp terminals, which seems to me to be nearer commercial conditions inasmuch as these are constant-potential rather than constant-current lamps.

Furthermore, the dust was removed from the reflector and tubes each time readings were taken during the life tests. Both the alternating-current and direct-current tubes are still operating These curves represent tests on one lamp of each type.

In the above-mentioned laboratory probably more arc lamp photometry is done than in any other laboratory in this country. And the experience of those who have conducted such work has

been that consistent results can be obtained on arc lamps if a number of tests are made on several different trims and readings taken by at least three different observers. If time will not permit of tests on more than one trim the curve should be marked as representing one lamp only.

I have some figures here from a life test just completed on a 5-amp. direct-current multiple enclosed arc lamp, equipped with clear inner globe only and ½ in. solid carbon electrodes which show a decrease in mean hemispherical candle-power of 10 per cent. at the end of twenty-five hours and 26 per cent. at the end of one hundred and forty hours, while the mean spherical candle-power showed a decrease of 10 per cent. at the end of forty-five hours and 13 per cent. at the end of 140 hours. The total life with an upper carbon 12 in. long and a lower carbon 5 in. long was 153 hours. Two sets of readings taken near the middle of this test showed the same phenomenon which Mr. Stickney mentioned and explained, namely, an increase in total flux. This test represents one trim only.

I think Mr. Millar's criticism of the tabulated data on arc lamps is justified. The authority for these figures should be given. Mr. Millar also called attention to the difference between the figures given in this tabulation for the direct-current series vertical carbon flame arc lamp 78 volts, 6.6 amperes, and the figures given by Mr. Ryan at the National Electric Light Association convention in St Louis last year. It was not until some time after this convention that our twin-mirror arc lamp photometer was completed and ready for testing so that Mr. Ryan in preparing his paper found it necessary to take a test made on a single-mirror photometer. It was a comparatively new illuminant at that time and both the electrodes and equipment of the present standard lamp to-day differ from those used for the curve in Mr. Ryan's paper. On the fourth page of that paper will be found the following statement in reference to the Boston flame arc. "While this is an index of what the lamp is doing in the present stage of development the characteristics and efficiency may undergo certain changes either for the purpose of increasing the life of the electrodes or improving the distribution and should not be regarded as final." Even the figures given

by Mr. Ashe may have to be changed before long due to improved electrodes. In fact this is the trouble in publishing extensive tabulations of this kind, especially if they include comparatively new illuminants. Changes and improvements are constantly being made, particularly in electrodes, so that in six months or a year figures now correct may not be applicable.

Some of the figures in the tabulation are taken from tests made at the laboratory which I represent and we are prepared to stand back of them and feel confident that they can be checked within 10 per cent. at any time by using the same make of electrodes and equipment if proper care is used in making the test. The rest of the figures given, while not taken from tests made by us, are within 10 per cent. of our figures on the same units and are within the limits of commercial photometric tests on arc lamps.

Our arc photometer is of the twin mirror type, which tends to give a much steadier light on the reading screen than the single-mirror type, and takes much less time to make a test. It also gives the average candle-power instead of the maximum and minimum which it is necessary to take with the single-mirror type.

Mr. Norman Macbeth:—I quite agree with Mr. Millar on a number of points which he has covered and on which I might possibly have taken a similar stand. The question of how to rate a light source whether from a distribution curve, the total flux, or the flux within certain zones is of particular interest and undoubtedly depends largely on the point of view. When one considers light sources for the purposes of illumination, the rating should be considered from the standpoint of the actual conditions under which that source is to be used. This consideration would be met through Mr. Millar's suggestion of co-efficients of utilization.

As some members here know, I have had two or three discussions recently on this question of allowing seventy per cent. as a reasonable reduction factor on laboratory tests of inverted gas lamps. This figure was one which I have frequently used as a depreciation factor to apply to "point to point" or flux calculations, as it was necessary to have some such factor to bridge between nearly ideal laboratory conditions, and practical every

day gas conditions varying as they do in different parts of the country and also to cover the average depreciation of mantles and glassware on regularly maintained installations.

To apply that same factor to the mean spherical candle-power from a lamp, equipped with a reflector directing 90 per cent. of the flux into the lower hemisphere, and compare that value with the mean spherical candle-power of a bare incandescent electric lamp, generating equal proportions of light in the upper and lower hemispheres, and with the flux determination entirely under laboratory conditions, is a somewhat different proposition. The efficiency of utilization is very much higher with the inverted gas lamps than it is with the bare incandescent electric lamps.

This paper would have been very much more valuable, had it left out some of the data here given, and I would apply that particularly to the candle-power depreciation figures on tungsten lamps. I can only speak for the gas tests with which I have been credited; the factors there given were practical utilization factors, which take into consideration average conditions of maintenance, average glassware, and not always good gas conditions. To consider the life curves of electric lamps under ideal voltage conditions, and with selected lamps is not fair. One should have somewhat similar results from tests on actual installations to compare with the gas lamp factors, and if Mr. Ashe did not have such figures, I think these life curves could more properly have been given in the usual bulletin of the lamp manufacturer.

One page 507 where the effective lumens per lamp are given, the actual lumens effective were secured from measurements on existing installations, and I can say positively that on that work no adjustments of lamps were made, and no attempt was made to get special installations. On the installations reported here I had no rights other than those of the man on the street. We simply went into the various locations, in different cities, choosing a time when the people in the store were not busy. It is largely for this reason that I feel that results secured in this way, under ordinary commercial conditions, should not be used in comparison with drawn-wire tungsten lamp tests, or any similar report of laboratory performances. Such figures should be withheld until installations can be made and reported upon in a

similar manner, taking into consideration glassware absorption. off-voltage of service and lamps, and in general the utilization of such equipment. If we propose to stand for the advancement of illumination, whatever the source may be, let us be fair. If we stand for the particular advancement of electric illumination we can readily produce facts which may be admitted to our advantage but without that unnecessary sting of partiality.

In the pilot tests, if Mr. Ashe had stated that the tests were made on Public Service gas in Harrison I think the qualifications would have been valuable. The pilot consumption is less with gas in some other places and greater again elsewhere.

The point was made in a paper given last week before the National Electric Light Association that pilots were convenient, enabling the ready turning out of a lamp when it might not be required for an hour or so. Should it not be considered then that a lamp will be less continuous in use when equipped with a pilot, and that therefore the total gas used for that lamp might be less when so equipped?

Mr. Ashe (Communicated in reply):—In Mr. Macbeth's discussion I note the statement that owing to the natural downward distribution of an inverted gas lamp, more useful light flux is distributed in the lower zones. This point is referred to in Mr. Harrison's discussion, in which it is shown that if a comparison is made on the basis of the amount of light in the 60-degree zone, plus one-half of the remaining light, that the values come out slightly in favor of the gas lamp, where a comparison is made between a 60-watt tungsten and a single inverted high efficiency gas mantle.

Regarding the 70 per cent. factor on gas tests, at a recent meeting of the National Electric Light Association, Mr. Macbeth stated that he felt that this value was a conservative one. I note in his discussion on my paper that he agrees to the 70 per cent. factor as he has used it frequently.

It should be noticed that the 70 per cent. factor which is given is a very much higher factor than the actual tests on street lamps indicated. For instance, Dr. Bell found that the average performance of the lamps was only 31.7 per cent. of the initial candle-power. Therefore, although the street lamps operate under severe conditions, ample margin has been allowed for

such factors, as bad regulation which have not been allowed for in the tungsten lamps.

Regarding the utilization factor which Mr. Macbeth mentions, I see no reason why, where there is such a wide allowance in the factor for gas between that actually obtained as indicated by Dr. Bell's figures and that calculated that the laboratory performance of a tungsten lamp should not be accepted as almost equivalent to that of its service use. Aside from dust collecting on the lamp, which is also true of the gas lamp, there is nothing except bad voltage regulation which will effect the life performance of tungsten lamp.

Moreover, the life of a lamp is decreased with an increase of voltage, and is increased with a decrease in voltage. In other words, one of these factors is continually offsetting the other.

Mr. Ward Harrison (Communicated) :—Mr. Ashe's paper seems especially timely. Where a comparison is required between illuminants, it must be made upon a scientific basis; we are all familiar with tables purporting to show the operating cost per candle-power hour for various illuminants in which the term candle-power refers in the case of one lamp to horizontal intensity, in another to mean hemispherical candle-power, in another to mean hemispherical candle-power, in another to maximum intensity and in the fourth to a merely nominal rating.

It is often difficult to decide upon what basis comparisons should be made, but I quite agree with Mr. Ashe that whatever basis is chosen, the average intensity during the life of the lamp or renewal part must be considered.

Of all general methods of comparison, that based on mean spherical candle-power or total lumens is probably the safest and least likely to lead to serious error. Where the comparison is made for one particular class of service, it is often advisable, however, to take into account the distribution of the light flux. For commercial installations some consider a comparison based on mean spherical candle-power sufficient, while others maintain that the light flux within the 60° zone is alone of importance. Both methods are open to some criticism; a better solution probably lies between the two. Personally, I believe that the flux within the 60° zone plus one-half of the remaining flux usually

forms a fair basis of comparison in such installations. It should not be assumed, however, that in the case of either illuminant all this flux would be effective on the working plane; in fact the width of a room would have to be three and one-half times the mounting height of a centrally located light source if all the flux within the 60° zone were to reach the working plane. Some light is, of course, required for the illumination of walls and ceiling and a considerable proportion of this may be reflected to the plane. When the walls and ceiling are dark, a considerable amount of light in the upper hemisphere is even more necessary to give the room the appearance of being well illuminated. The difference in results obtained by the three methods of comparison cited above is illustrated in the case of two units widely used in commercial lighting, inverted gas burners and tungsten-filament lamps equipped with prismatic reflectors. Curves made by the Electrical Testing Laboratories show that fully 68 per cent. of the light from an inverted gas burner equipped with a reflector is emitted within the 60° zone, while in the case of tungsten-filament lamps with reflectors approximately 57 per cent. of the flux is so directed; hence comparisons between these units made on a mean spherical candle-power basis differ widely from those based on zonular flux. If one-half of the light outside of the 60° zone is added, 84 and 78.5 per cent. of the light from the gas and tungsten filament units, respectively, would be taken to represent their relative values. On this basis an inverted gas lamp having a mean spherical candle-power 6.5 per cent. lower than that of a tungsten-filament unit would be considered its equal as an illuminant. I believe that this figure represents fairly well the advantage possessed by the inverted gas unit, due to its inherent downward distribution.

The candle-power performance of gas lamps is discussed rather fully in the report of the Committee on Competitive Illuminants of the National Electric Light Association which was presented at the 1911 convention. In this report are given the results of several tests of well maintained installations in addition to those cited by Mr. Ashe. These tests would indicate that the figure of 70 per cent. given by Mr. Ashe as representing

the ratio between service and laboratory candle-power tests on gas lamps to be rather high. The question as to what percentage of the initial candle-power of a gas lamp should be taken to represent its average performance under service conditions is one deserving of the most careful consideration.

It is evident that when given a "fitters adjustment" a gas lamp will not produce such a high candle-power as can be secured with accurate adjustment on a photometer bar. The loss due to this cause has been stated to be about 10 per cent. During the lecture course in illuminating engineering at Johns Hopkins University last fall life tests on high-grade inverted mantles were given which showed an average candle-power during the first thousand hours above 95 per cent. of the initial candle-power. Consequently if there were no further differences between laboratory and service conditions, the rated candle-power of a gas lamp would not have to be discounted more than 15 per cent. to cover both the inaccuracy of a fitter's adjustment and the deterioration in candle-power of the mantle throughout life.

Some very exhaustive tests of the illumination produced by gas lamps were conducted two years ago in the laboratory of the Welsbach Company under the direction of Mr. Norman Macbeth. In these tests an efficiency of approximately 330 effective lumens per lamp was obtained for inverted mantles operated with prismatic reflectors in a room with dark walls and a light ceiling; assuming the rated consumption of the burners this figure corresponds to an efficiency of 100 lumens per cubic foot. The 24 lamps used in the tests were adjusted by the eye for maximum incandescence, and the pressure was then held constant at 2.2 inches while the photometric readings were taken. Similar tests were also conducted in a room with a lighter wall covering, and the effective illumination was thereby increased approximately 10 per cent.

In the service tests on gas lamps quoted in Mr. Ashe's paper, which were credited to Mr. Macbeth, an average of 70 per cent. of the efficiency shown in his laboratory luminometer tests was secured. These laboratory tests already included the allowance of 10 per cent. for the inaccuracy of a fitter's adjustment; hence there must be other reasons for a further reduction of

30 per cent. from the laboratory figures. I believe that this reduction is due in a large measure to two factors: (a) the deposit of dirt which collects on the mantles and in the passages of the burners, and (b) those fluctuations in gas pressure and change in quality of the gas which make a readjustment necessary, if the lamps are to be maintained at their highest efficiency. A part of the reduction from the laboratory efficiency might also be attributed to the collection of dust on the reflectors and globes, but I am inclined to believe that in the case of well maintained installations such as those cited above, where the glassware is cleaned as often as once in two weeks, the depreciation due to the collection of dust on the exterior of a gas unit is almost negligible.

After gas burners have been in use for some time particles of soot from the gas and also particles of dust from the atmosphere find their way into the burner and clog the ports, thus preventing the proper mixture of gas and air. It is practically impossible to remove this deposit completely without taking down the burners and giving them a most thorough overhauling. A single example will serve to illustrate this point. Some time ago a department of the company I am connected with desired to make candle-power tests on an inverted mantle, which had been in use off and on for a considerable period. Instructions were given to the man in charge of the test to clean the lamp well before making any measurements. He gave it the same amount of attention as would probably have been accorded to it by a good maintenance man at the time of changing the mantles. He then put on a new mantle of the best quality, adjusted it for maximum incandescence with the assistance of a photometer screen, and secured an intensity of 43 candle-power. This figure seemed rather low and the lamp was turned over to a second operator, who cleaned the parts thoroughly and ran a fine pointed instrument through all the gas and air passages so that every particle of dust was removed. The lamp was then tested with a new mantle under the same conditions as before, and an increase of 32 per cent. in candle-power was obtained. I was present at each of the tests and can state positively that every effort was made to secure the highest possible candle-power from the lamp in both instances.

Besides the deposit of dirt which tends to clog the burner, a considerable quantity of dust settles upon the mantle when not in use, and its presence reduces the candle-power life curve of the mantle below that which would be secured in a laboratory under conditions of continuous burning.

Gas lamps under a maintenance contract are usually inspected about once in two weeks, or at best once a week. It is evident that adjustments made at such intervals cannot take care of the fluctuating pressure on commercial gas lamps or of changes in the quality of the gas.

As the result of considerable investigation along these lines, I would corroborate Mr. Ashe's statement that under good conditions of maintenance the average intensity obtained from an installation of gas lamps will be about 70 per cent. of the intensity produced by the same lamps when first installed. In addition I might state that during the past few months I have had occasion to go through the proceedings of the National Commercial Gas Association, of the American Gas Institute, and of the Illuminating Engineering Society; also through the files of the American *Illuminating Engineer,* of the London *Illuminating Engineer,* of *The American Gas Light Journal* and of the *Progressive Age.* I could not find a single test recorded in any one of these publications during the past five years which would indicate that the average intensity of a gas burner in service is more than 70 per cent. of its candle-power when first installed. There was one test recorded in which the rated efficiency of the burners was secured, but these lamps had only been installed two weeks, when the measurements were taken, and there was no statement to show that the lamps had not been adjusted for maximum incandescence just prior to the test.

Mr. Ashe has shown candle-power life curves of the drawn wire tungsten lamp and has stated that the average candle-power during the first thousand hours of burning at 1.18 watts per candle is equal to 94 per cent. of the initial candle-power. I believe that this represents quite closely the performance of the average drawn-wire tungsten lamp. The lamps in these tests burned for considerably more than a thousand hours; the average candle-power will, of course, depend largely upon the figure

which is taken to represent their average life. The total cost of producing light is, however, to a great extent independent of the total life of the lamps. Extensive calculations which have been made in the engineering department of the National Electric Lamp Association show that the cost of producing light with a lamp having a life curve such as is given in Mr. Ashe's paper, will not be appreciably different whether the lamps are assumed to have reached their smashing point at 85 per cent. or at 75 per cent. of the initial candle-power. It is not a matter of great importance, therefore, what life is taken for the incandescent lamp, provided that in the cost calculation there is used the average candle-power which corresponds to that life. In this respect the tungsten lamp might almost be termed "self-regulating."

If one is to judge gas lamps on the basis of average candle-power under service conditions the same standard must, of course, be applied to the other illuminants considered. The conditions which effect the performance of the incandescent lamp in service, which may not be present in the laboratory test are (a) accidental breakage, (b) fluctuation in line voltage, (c) difference between the labeled voltage of the lamp, and the average voltage of the circuit, (d) collection of dust on lamps and reflectors.

The effect of accidental breakage upon the cost of producing light is under most conditions almost negligible, for the reason which I have stated above; namely, that if lamps are smashed at either 75, 80 or even 90 per cent. of their initial candle-power, the cost of power and renewals which will be required to produce a given quantity of light will not be altered more than a few per cent.

Computations in regard to the effect of fluctuating voltage upon the preformance of incandescent lamps show that even if the voltage varies as much as 4 volts on either side of the mean value, the average cost of producing light per 100,000 lumen hours will not be materially affected. Should the voltage fluctuate as much as ten volts on either side of the mean, it would be advisable to purchase a lamp labeled about one volt higher than the average voltage of the line, and under these circumstances the cost of producing light might be slightly increased.

Where lamps are not operated at their rated voltage the cost of lighting may be considerably increased, although the decrease in life on over-voltage in the case of the tungsten filament lamps, is to a considerable extent compensated for by their increased efficiency. In my opinion, however, it is scarcely necessary for the members of this society to consider the effect of operating lamps at the wrong voltage when speaking of good service conditions. It would seem that any engineer interested in the economy of light production would at least see to it that the lamps used on his circuit are labeled within one or two volts of the average voltage of the line.

The factor which constitutes the chief difference between laboratory and service tests on incandescent lamps is the collection of dust on lamps and reflectors. Simply because the incandescent lamp does not require attention at frequent intervals it has been considered by some quite unnecessary to clean the reflectors. I believe that it is quite as necessary to clean the reflectors of a tungsten installation, as it is to clean and adjust gas lamps, and that a proper allowance for this cleaning should be made in cost computations. Tests are sometimes published to show that the depreciation due to dust on an installation of incandescent lamps may be as high as 30 per cent. It should be remembered, however, that in most cases these installations have been allowed to operate for four or five months without any attention. If the lamps were cleaned once a month, the total depreciation during that period would not be more than 6 or 7 per cent., and the average loss due to dust would be but three or four per cent. I can see no reason, therefore, why laboratory life tests on incandescent lamps should be discounted more than four or five per cent. to represent good service conditions.

In the candle-power life tests of mercury-vapor lamps given in figures 8 and 9 average candle-power values were shown to the end of the test periods, which I believe would not represent the total life of the lamps. The life of mercury-vapor lamps is ordinarily rated at 4,000 hours and if the curves were produced to this point, the average values would be considerably lower than those given; in fact if there were no depreciation whatever beyond the points to which these tests were run, the average candle-

power during life for the 45-inch direct-current lamp would be 55 per cent. and for the 50-inch alternating-current tube 62 per cent. of the initial candle-power. Other tests with which I am familiar show that the candle-power continues to fall off from 3 to 5 per cent. in each succeeding 1,000 hours.

At this point it may be of interest to note (Fig. 20) the results of a test of two 21-inch mercury-vapor lamps which has just been completed by the engineering department of the National Electric Lamp Association. The lamps were operated on a circuit, the voltage regulation of which was better than 0.5 per cent. Every precaution was taken to insure accuracy of photo-

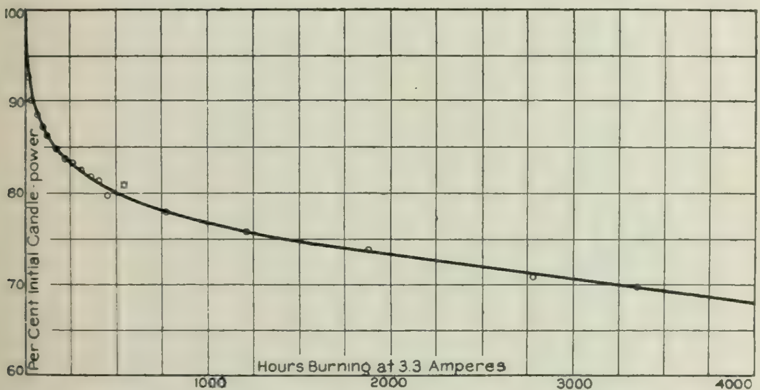


Fig. 20.—Candle-power performance of two 21-inch, 55-volt, direct-current mercury-vapor lamps operated at rated voltage.

metric work. The auxiliary was adjusted for the line voltage and in this case the actual current consumption was 3.3 amperes instead of the rated 3.5 amperes. I am unable to state what difference this would make in the life of the lamps. However, if a life of 4,000 hours at 3.5 amperes were equivalent even to 6,000 hours at 3.3 amperes, the average candle-power during the rated life would be reduced only from 75 per cent. to 72 per cent. of the initial candle-power.

I do not consider that a sufficient number of lamps were tested to warrant the statement that this curve represents the average performance of 21-inch lamps; nevertheless the data indicates that the average candle-power of these lamps is considerably higher than that Mr. Ashe found for the larger sizes.

The distribution curve given in Fig. 15 for two 21-inch mercury-vapor lamps shows 288 mean spherical candle-power, which should be corrected to 295 or 300 mean spherical candle-power for operation at 3.5 amperes.

The curve in Fig. 11 for 45-inch lamps shows 398 mean spherical candle-power. I can scarcely believe that the gain in efficiency, due to the use of long tubes, is as great as these tests indicate. Data presented by Dr. Pole before this society last April show the candle-power per inch emitted by a mercury-vapor lamp on constant current to be almost independent of the length of the tube.[1] One would expect, therefore, that the total light flux emitted from a 45-inch lamp would be approximately 7 per cent. greater than for two 21-inch lamps. I believe that the greater difference in candle-power shown by curves 11 and 15 is due to the fact that the curve of the 45-inch lamp represents readings taken in one plane only.

The exceptionally complete table of the performance of arc lamps, which is included in Mr. Ashe's paper, is certainly a valuable contribution. In most cases the figures given for candle-power and efficiency check very closely with data which I have been able to secure on these units.

I have found the forms shown in Figs. 21, 22 and 23 to be of considerable value in recording data on illuminants in such form as to admit of ready comparison. A blank sheet for references is usually used in conjunction with the three forms here shown. The idea of recording data in regard to various illuminants on uniform sheets of this character originated with Mr. J. S. Codman. I believe that if the sheets as here presented are carefully filled out, it will be possible to draw comparisons between illuminants which will take into account all factors and which will be absolutely fair to both units under any given set of conditions.

One cannot reasonably expect that individual tests on arc lamps will agree within 10 per cent. because of the difference in carbons, globes, etc. It would appear that the life of electrodes given in this table is the life which would be secured in a laboratory test. In most instances the full rated life of the carbons cannot be obtained under service conditions. Frequently it is

[1] TRANS. I. E. S., Vol. VI, page 336.

DATA FORM

Investigation No. .... Sheet No. 1.

Complete in .... Sheets.

Type of Illuminant ....

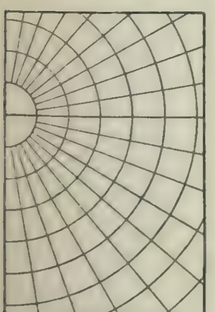
Trade Designation ....

Manufacturer ....

Power or Fuel Used ....

....

	Manufacturer's Rating		Average Performance	
Volts				
Pressure				
Amperes				
Frequency				
Watts				
Cubic Feet per Hour				
Burner				
Pilot				
B. t. u. per cu. ft.				
Flux	M. C-P.	Lumens	M C-P.	Lumens
Spherical				
Hemispherical				
60° Zone				
Effective Lumens				
Light Walls				
Dark Walls				



Equivalent Capacity in Tungsten Filament Lamps........... Watts.

Equipment.

....

....

....

....

....

....

....

Fig. 21.—Specimen sheet No. 1 of a record for test results, statistics and data pertaining to an illuminant.

Investigation No. .... Sheet No. 2.

INITIAL INVESTMENT

	Permanent Parts	Renewal Parts	Life of Renewal Parts Hours
Appliance			
Reflectors			
Holders			
Sockets			
Cut-outs			
Pilot Attachment			
Lamps			
Mantles			
Tubes			
Glowers			
Heaters			
Ballasts			
Economizers			
Chimneys			
Outer Globes			
Inner Globes			
Positive Electrodes			
Negative Electrodes			
....			
....			
....			
Total Investment in Permanent Parts.........	....		
Total Investment in Renewal Parts..........		....	

Total Initial Investment ....

Discounts ....

....

....

....

....

Fig. 22.—Specimen sheet No. 2 of a record for test results, statistics and data pertaining to an illuminant.

Investigation No. .... Sheet No. 3.

OPERATING COST

(1) Annual Fixed Charges
- (a) Rental Including Maintenance ....
- (b) Interest, Insurance, and Taxes
  on Total Investment....% ....
  Depreciation on Permanent Parts ....% ....
  Maintenance Service ....
  Total ....
- (c) Interest, Insurance and Taxes
  on Total Investment....% ....
  Depreciation on Permanent Parts ....% ....
  Labor for Cleaning and Adjustment......................
  Total ....

(2) Maintenance per ....
- (a) Lamps ....
  Mantles ....
  Tubes ....
  Glowers ....
  Heaters ....
  Ballasts ....
  Economizers ....
  Chimneys ....
  Outer Globes ....
  Inner Globes ....
  Positive Electrodes ....
  Negative Electrodes ....
  Repairs ....
  Labor, Trimming ....
  Inspection ....
  ....
  ....
  ....
  Total ....
- (b) Maintenance Service at .... per Kw-hr.

(3) Energy Cost per 1,000 Hours
.... at .... per ....
Cost of Pilot Consumption for 8,760 Hours..................
....
....

Fig. 23.—Specimen sheet No. 3 of a record for test results, statistics and data pertaining to an illuminant.

not feasible to so time the trimming periods that the electrodes are completely consumed; in some types of lamps a considerable amount of the electrode material is burned away when the lamps are first lighted and the total life per trim will, therefore, depend to a certain extent on the number of times the lamps are turned on and off. This characteristic is especially marked in some flaming arc lamps.

Mr. C. O. Bond:—I quite agree with Mr. Ashe on the need of a proper basis of comparison for different illuminants and think his suggestion that illuminants should be compared on average candle-power performance throughout life is in the right direction. My only criticism of it is that he does not go far enough.

Mr. Ashe states: "that (the candle-power) is what the consumer pays for, and it seems that this is the one fair basis of comparison." If lighting companies could sell their product in units of illumination, this would be correct, but, as a matter of fact, the consumer does not pay for candle-power, but for the energy consumed in the production of the candle-power. Take, for instance, the drawn wire tungsten filament lamp, which Mr. Ashe gives in his final table as having an average of 94 per cent. of its initial candle-power throughout its life when operated at 100 volts. The consumer continues to pay for his full rate of energy while the light which he receives averages only 94 per cent. of this.

In the case of the gas mantle mentioned, in which case Mr. Ashe credits a high-grade mantle with averaging only 70 per cent. of its initial candle-power—this mantle may be visited regularly by the maintenance man and the gas readjusted as is required by the shape of the mantle, and while the assumed average candle-power may have fallen to 70 per cent., yet the input of energy has fallen also, so that the ratio of energy input to light output may have changed but little.

It is regrettable that a variety in quality of mantles and in quality of gas lamps does exist and probably the way is not yet clear to establish uniformity in this matter; but the future may bring that uniformity just as it has in the production of electric light units in recent years.

I think, however, that inasmuch as the final table of efficiencies given by Mr. Ashe has been drawn so largely from lab-

oratory results, that the same privilege in the statement of efficiencies should have been accorded the gas mantle, particularly as he has mentioned it as a high-grade mantle.

The rating of gas lamps at the United Gas Improvement Company's photometrical laboratory is based on their efficiency in terms of lumens per British thermal unit. Thus the entire luminous flux from the lamp per unit energy input is used. In mantle tests the factor of efficiency adopted is the number of British thermal units input per mean horizontal candle-power output. This factor offers a comparison between different mantles of the same type. The relation between horizontal and mean spherical candle-power in each of two types of mantles remains fairly constant.

I give below some figures showing the difference in the method of rating mantles as suggested by Mr. Ashe on the basis of average candle-power and on the basis I have suggested of light production from energy input. Each of the figures given is the result of tests of six mantles of different make. In the tests forty mantles were used in each case. It should be stated also that these mantles were removed at the end of each test period and carried into an adjoining room for the purpose of candle-power determination, so that there was considerably more handling than the average mantle in service would receive.

While in all instances there is a peak in the life curve of mantles, yet this peak occurs usually within the first one hundred hours. The shape of the curve, however, from the initial reading to the one thousand hour reading approximates a straight line. The table which I give is one of percentages, the figures in each case being the result of dividing the first hour results into the one thousand hour results.

TABLE I.—UPRIGHT MANTLES.

$\frac{\text{H. C. P. (1000 Hr.)}}{\text{H. C. P. (1st Hr.)}}$		$\frac{\text{B. t. u. per H. C. P. (1000 Hr.)}}{\text{B. t. u. per H. C. P. (1st Hr.)}}$
85.0		83.8
45.7		63.0
52.8		80.0
52.4		74.0
65.4		76.3
72.2		89.2
62.5	Average	77.5
81.25%	Average efficiency	88.8%

TABLE II.—INVERTED MANTLES.

96.0		99.5
93.0		110.0
91.6		99.0
76.5		75.4
79.0		80.8
102.51		105.5
89.8	Average	95.04
94.9%	Average efficiency	97.5%

In the above-given mantle tests if a small hole developed in the mantle, and its area remained so small as not to interfere with the proper incandescing of the entire mantle, the mantle was continued in the test. I offer these figures as showing the efficiency which is possible by the correct use of the mantle.

If a mantle becomes carbonized through excess of gas or deficiency of air, or violent draughts, it is possible for one who understands, and will take the trouble, to burn this carbon off and renew the efficiency of the mantle with little or no injury, but right at this point is where appreciable losses in efficiencies occur. Many people, too, through ignorance or indifference permit the accumulation of carbon until the mantle breaks down under the load. A proper maintenance system averts this trouble.

Mr. Ashe's table of the consumption of gas by pilot flames is not clear to me. I have found the smallest escape of gas which, in a quiet atmosphere, will continue burning to be 1/40th of a cubic foot per hour. One-fiftieth of a cubic foot burns only intermittently. In a test recently made on the type of pilot now furnished with the reflex burner mentioned in Mr. Ashe's table consumed under 2.5 in. pressure 1/10th of a cubic foot per hour, when adjusted to a flame length of ¼ in.

Mr. Ashe (Communicated in reply):—In replying to Mr. Bond's excellent contribution, I include a paragraph of my original paper, which was omitted inadvertently in printing the accompanying paper. This paragraph was intended to be inserted at the end of the material on gas lamps.

"In considering the question of the performance of the gas mantles, the matter of the efficiency of the mantle is some times introduced. As the mantle burns, the mantle shrinks. Consequently, a smaller volume of gas is required to illuminate the entire mantle, which, if careful adjustment of the burner is made, keeps up the value of effective lu-

mens generated per cubic foot of gas consumed. Statements have been made to the effect that some mantles have been tested on which the efficiency is 100 per cent. on this basis of comparison."

This is inserted simply to show that I had anticipated this method of rating. It does not seem, however, that this method is entirely commercial. Owing to the ordinary operation of gas mantles, even where the mantles are maintained by the gas companies, the maintenance charge would become excessive, if an attempt were made to continually adjust the burner to afford values like the laboratory values which Mr. Bond gives.

According to Mr. Bond's figures, it seems to make considerable difference whether this adjustment is made or not, as in one case for the upright mantle a value of 62.5 per cent. is given, whereas the value where the adjustment is made is 77.5 per cent. Furthermore most consumers do adjust their burners occasionally. The frequency of the adjustment usually increases as the mantle reaches the end of its life, and an attempt is made to get an increased candle-power from it.

Mr. Bond makes the statement that the consumer continues to pay full rate for energy for the tungsten filament lamp, while the light he receives averages only 94 per cent. of this. Mr. Bond evidently did not have the energy life curves of the tungsten lamps before him when writing; for he would have noticed that at the end of one thousand hours the energy input for the 100-watt lamp falls to 96 per cent. of the initial input. This is a characteristic of lamps of this type; as the candle-power falls slightly, the energy consumption also falls slightly. There is a small difference of energy which the customer pays for, for which he does not receive light, but this can be readily seen is an extremely small quantity, and compared with gas lamps, the same factor would probably be greater for the gas, as Mr. Bond's figures tend to show.

It is interesting to note the values which Mr. Bond gives for laboratory-tested high-grade gas mantles. The high character of the work which Mr. Bond does and of what he has published in the past warrants the acceptance of these results as a valuable addition to the data on the subject. It would have been more interesting if he had given figures which show the service depreciation over laboratory depreciation of gas mantles. From

the results published by various authorities, it seems that the actual service depreciation is very heavy. On the other hand with the tungsten lamp, as has been stated in other discussion, it is so slight that it is only in cases of extreme voltage fluctuation that the deterioration in service is of such magnitude as to be considered. Service tests which have been made on a well regulated system tend to indicate that there is practically no difference between service values and laboratory values so far as average candle-power performance of tungsten lamps is concerned. Owing to increased vibration and rough handling, the average life of the lamp is shorter than the laboratory life, but this has nothing to do with candle-power performance. Where the lamps are kept clean, I see no reason, as previously stated, why it is not fair to compare laboratory values, or service values which are the same as laboratory values, with the service values of gas lamps. There are so many factors which affect the performance of gas lamps, which do not affect the performance of tungsten lamps that the above facts are self-evident to any one who has studied this subject carefully.

Mr. J. B. Klumpp:—I notice in Mr. Ashe's paper, on page 506, a reference to an article in the *Electrical World* of August 18, 1910, of tests made by the Merriam Commission of Chicago, on the gasoline street lighting in that city. These tests are so stated as to leave an impression that the results represented the average condition of the entire number of lamps in the service; whereas, the list quoted only includes some thirteen lamps, and the fact was that only about fifty lamps were tested out of more than seven thousand in use. The results of these thirteen lamps quoted it will be noted, averaged only 29.9 candle-power.

The article mentioned in the *Electrical World* gives one an impression that the representative of the contracting company assisted in the testing; whereas, he was present only on sufferance and had no voice in the selection of the lamps tested. It is known, also, that the testing party passed hundreds of well appearing lamps before selecting the abnormally low ones which were tested and results of which are quoted in this report. It will, also, be noticed that a lamp as low as 1.9 candles is included in the average. Under ordinary conditions such low candle-powers are considered outages, and generally mean a broken

or fallen mantle. No reference is made in the article that these lamps were based on (according to the contract) delivering a Hefner candle, which is only 0.9 of the international candle.

A test made later, in August, 1910, under the same contract, by the city's gas tester, in conjunction with the contractor's engineer, on 150 lamps, showed that these lamps averaged 63.75 Hefner candles. The results of this test are shown in the accompanying table.

On September 1, 1910, a new contract was made with the same company and sixty international candles were demanded, and the following tests show the result of a monthly investigation by the city's gas tester, in conjunction with the contractor's representative. Under the new contract the lamps are selected in such manner as to give the contractor a fair representative test. Ten consecutive lamps are taken in each of fifteen selected localities, which demands that the good lamps shall be tested as well as the bad ones; which was not the case in the test made by the Merriam Commission.

During the winter months candle-power tests of lamps were not made, but visual inspections of some six or eight hundred lamps were made monthly by the city's testers and the lamps were reported as giving satisfactory service.

It might be noted that under the present contract, no deductions are made for lamps unless they fall below forty-five candle-power, and all lamps giving fifteen candle-power or less are considered out.

Month	No. Lamps Tested	Above 60 C-p.	44 to 60 C-p.	Below 45 C-p.	Average C-p. Obtained Hefner	International
	Reported by Contracting Company					
Aug., 1910	150	99	..	..	63.7	.....
Oct., 1910	150	96	45	9	....	62.99
Nov., 1910	35	24	11	0	....	64.10
	Reported by City Gas Tester					
Mar., 1911	150	98	47	5	....	63.30
Apr., 1911	150	93	52	5	....	62.44
May, 1911	150	68	68	14	....	58.60
June, 1911	150	104	41	5	....	46.20

J. R. Cravath (Communicated) :—Regarding the condition of gasoline street lamps in Chicago during May and June, 1910, at the time investigations were being carried on by the engineers

of the Merriam Commission, I wish to state that this particular investigation was in charge of W. H. Zimmerman & Company of Chicago, who in turn employed me to make candle-power tests on gasoline and other street lamps. The engineers connected with these tests on behalf of the Merriam Commission stand responsible for their fairness and accuracy. Mr. Klumpp was not present at any of these tests and has evidently been misinformed on a number of important points.

Every effort was made to have the tests made on these gasoline lamps represent the average conditions. The method employed in selecting lamps for tests was as follows. The day before each test the engineers in charge of the investigation consulted a map of the city showing the location of gasoline lamps, and on this map selected at random without any knowledge of local conditions, a locality in which a number of gasoline lamps were being operated. The locality selected was not announced until all concerned were ready to start for the place of testing that evening. Upon arriving at the locality where the testing was to be done, the test was begun at a place selected at random and from then on the lamps were tested consecutively along a street or route until the work in that locality was finished. In this way, we believe, the tests represented as near a true average as was possible from testing such a limited number. The fact is, the real conditions were considerably worse than indicated by the few tests quoted in Mr. Ashe's paper. The tests in his paper were made only after the gasoline lighting company had knowledge that an investigation was going on, and therefore had opportunity to improve its lamp condition. Twenty preliminary tests showed an average of only 19.4 candle-power. During the latter tests the gasoline lighting company was represented by Mr. F. V. Westermeier as its expert and the city electrical department of Chicago which has charge of street lighting was represented by Mr. E. M. Tompkins its electrical engineer. Mr. Westermeier as an expert for the gasoline lighting company was present for the express purpose of seeing to the accuracy and fairness of the tests and to raise objection to any methods of procedure which he might consider improper. No such objections were raised and the whole affair went off harmoniously as far as the engineers and experts involved were concerned. However, the superintendent of the

gasoline lighting company did take some exception to our methods because he was not allowed to select some of the localities in which testing was to be done. As our effort was to get at the true state of affairs throughout the city rather than to test a few picked lamps specially prepared for test by the company, the absurdity of such a proposition needs no comment.

Since the Merriam Commission investigations were made, a new contract has been enforced which provides for rebates to the city when 150 lamps tested per month average below 45 candle-power, the test being made with the glass lantern door open instead of closed as in the Merriam Commission test. As a result of this contract, maintenance conditions of gasoline lamps have been so improved that I am now informed the candle-powers average in the neighborhood of 60 with the lantern door open. The improved conditions are manifest without the aid of any photometer. It is of course true that more tests would have been desirable to determine the actual conditions of gasoline lamps in Chicago at the time the Merriam Commission engineers began their work. However, the tests made represent average conditions as nearly as was possible with such a limited number of tests. The charge that bad lamps were selected for tests and good ones deliberately passed by, as made by Mr. Klumpp is absolutely without foundation. Had it been true it should have been made by the company's expert at the time of the public hearing of the commission on this matter and our method of procedure would also have been objected to by him during the tests. Furthermore, if the charge is true, it should be sufficient to ruin the professional standing of all the engineers connected with the tests and should be a matter for investigation by this society and other engineering bodies to which the engineers involved belong. I believe the condition of gasoline lamps in Chicago previous to this investigation was the result of ignorance by all concerned rather than intention or carelessness on the part of the company supplying the lamps. The investigation showed, however, the great importance of proper maintenance of mantel burners and the desirability of frequent candle-power measurements to insure a high grade of service from the lamps.

Mr. Ashe (Communicated):—Regarding the tests of the Merriam Commission to which Mr. Klumpp refers, I would state

that as Mr. Klumpp has evidently made a very careful investigation of this situation his communication is instructive because it gives a number of facts which have not been made public before. I am not, however, in a position to comment on this discussion.

One word before passing Mr. Klumpp's discussion, and that is that no values are given of actual replacements. It would be interesting if in connection with his data he could give the life values of the mantles tested, so as to indicate whether the maintenance of the present lamps is cared for on a basis similar to that which was in existance before the Merriam Commission made its report.

Mr. B. F. Fisher, Jr.:—I have been very much interested in Mr. Ashe's curves, and I would like to know, just how these curves were made. Have the early burn-outs been included? The figure of 94 per cent. as a "conservative value for the candle-power of the tungsten-filament lamp, during 1,000 hours," is rather striking, as I have been unable myself to decide as to just what that average value should be; and I would like to know whether it is a value eliminating early burn-outs on the test, as is sometimes done in giving the value of tungsten lamps.

Mr. Ashe:—Replying to Mr. Fisher's question regarding whether the curves included early burn-outs. I may state that Figs. 1 and 2 for improved tungsten lamps are average values including burn-outs from actual lamps tested, and represent the facts as found.

Mr. P. S. Millar (Communicated):—The author has presented in this paper arc lamp data which are of much interest and which should be valuable. They suffer, however, from lack of qualification. Consider, for example, the multiple enclosed carbon arc lamp equipped with an opal inner globe and a reflector. The candle-power and efficiency of enclosed arc lamps may vary with the type of regulation of the lamp, with the quality of the carbons, with the size and shape of the inner globe, with the absorption of the inner globe, and with the rate at which air is admitted to the inner globe. This latter may vary among different makes of lamps and among individuals of any one make, and it may vary with the fit of the globe against the globe cap. It may depend also upon whether the lamp is burned indoors or outdoors.

These possible variables have been ignored in this paper. To have stated that enclosed arc lamps of the type described have been tested repeatedly in certain laboratory, describing specifically the equipment of the lamp and the conditions of burning in each of the respects mentioned, and then to have presented the average value obtained, would have made this contribution more valuable. To present the data without the qualification here suggested makes the contribution liable to misapplication.

It has developed in the discussion of the paper that most of the tests were made in the well-equipped laboratory of a manufacturing company. This leaves in doubt the authority for some of the tests and, further, the question as to which tests were made in the laboratory referred to and which tests were made elsewhere. To those who desire to use the data discerningly, this constitutes an additional handicap.

Although it is not so stated in the paper, yet it is apparent that the arc lamp values presented are initial values, in spite of the fact that there is emphasized in the first part of the paper the importance of the average candle-power throughout life rather than the initial candle-power as a basis of comparison.

Personally, I feel indebted to Mr. Ashe for the data which he has made available. I believe that it is a valuable contribution to the TRANSACTIONS of this society and that it will be very useful to the members of the society at large, provided only that it is accepted as subject to application limitations of the character suggested above.

Mr. Ashe (Communicated in reply):—In view of the experience which Mr. Millar has had on arc lamp photometering, it seems unfortunate that instead of presenting communications in the nature of criticism, he should not present data, which he no doubt has in his possession, which would make both his discussions of my paper more valuable.

The purpose of presenting this paper was twofold: first, to establish the proper basis of comparing illuminants, with which Mr. Millar seems to be in agreement, as are the majority of those who have discussed the paper; second, to present a large amount of data which should be helpful in arriving at a conclusion as to the value of different types of illuminants. The data given have been collected at considerable expense. It was hoped that the

initiative taken in getting out data of this kind, would be followed up by other companies (a practice not in vogue at the present time), so that data from different reliable sources could be compared and final conclusions drawn. In all the data which have been presented, care has been taken to specify, either in the paper or in the discussion, where the tests were made, also the authority. There is no reason why one should doubt the data when the high character of those who have assisted in collating the data is taken into consideration. Any one particularly interested in this subject, who carefully reads the paper and my discussion need make no mistake in interpreting the data presented.

Mr. R. B. Hussey (Communicated) :—The basis of comparison brought out by Mr. Ashe, that of average candle-power life service, is a valuable one and while not new is one that is practically lost sight of in ordinary comparison. The principal difficulty appears to be in the determination of the useful life of the illuminant. This useful life will depend upon local conditions such as cost of power and conditions of service, steadiness of line voltage, etc. A fluctuating line voltage will materially reduce the useful life of a tungsten lamp and a continued jarring or vibration will affect the life of a gas mantle installation.

The average candle-power life figure is of value principally as a sort of correction factor to the efficiency and maintenance figures. Assuming for the moment that the table of average candle-power life figures are correct, it does not of necessity mean that the tungsten lamp, for example, is more efficient than the direct-current mercury-vapor lamp. The tungsten lamp from the curves given on page 505, makes an excellent showing when the lamps are considered to have a life of only 1,000 hours; but if the maintenance of the lamp is calculated on that life, it will be found to be high. On the other hand if the life be taken as is usual, at 1,300 or 1,700 hours, the average candle-power life will be lower but the maintenance will also be lower.

While there is undoubtedly some deposit on the globes of inclosed and luminous arc lamps which will reduce the effective candle-power during the life of a pair of electrodes the valuation given by Mr. Ashe seems somewhat low. Under ordinary conditions of service, the 4.0- or 6.6-ampere luminous lamp

should show a reduction in candle-power of less than 10 per cent. at the end of a trim, due to dust collecting on the inside of a globe.

In Mr. Ashe's table of arc lamp data, the specific consumption of the flame carbon lamp is somewhat higher than is being obtained at present from this type of lamp. For instance the present series vertical carbon flame lamp operating at 6.6 amperes and 78 volts should give a specific consumption of approximately 0.31 watts per mean spherical candle-power with a life of about 50 hours instead of 20.

Mr. Ashe (Communicated in reply) :—Mr. Hussey in his discussion of the relative merits of the tungsten and mercury-vapor lamps introduces the subject of maintenance. He infers that if maintenance is considered the comparison of the tungsten lamp with the mercury-vapor lamp will not be in the favor of the tungsten unit. But if Mr. Hussey will consider the high first cost of the mercury-vapor units, he will realize that when maintenance values are included that the comparison is still more favorable to the tungsten unit. It is impossible, however, to give actual cost comparisons owing to the rulings of this society, but if Mr. Hussey will compile the costs and charges for interest and depreciation, he will find the facts as above stated.

Regarding the factor of the candle-power life performance of the luminous arc lamp, I wish to state that the depreciation values given in the paper are the results of tests made in the laboratory of the General Electric Company in Schenectady, N. Y.

Mr. G. H. Stickney:—Although I am now more especially interested in incandescent lighting, I feel that I should say something at this time in favor of arc lamps. I refer particularly to the curve No. 16, which shows a very rapid depreciation in the light from an enclosed arc lamp in the first part of its life. Now it is quite possible that such a curve might be obtained under particular conditions, with one special style of enclosed arc lamp, but I do not think that it can be taken to represent the performances of the enclosed arc lamp as a class. In fact, I doubt if any single curve could represent all types of enclosed arcs.

While I have not the data at hand, I have very distinct recollection of a series of photometric life tests which I con-

ducted several years ago on the direct-current multiple 80-volt 5-ampere enclosed arc lamps, equipped with opalescent inner and clear outer globes. These tests showed an increase over the initial candle-power after the lamp had operated some fifteen hours. This was followed by a falling off in intensity toward the end. This falling off was nowheres near as marked as that shown in curve Fig. 16. I remember particularly the increase referred to on account of our study to explain it. At that time it was attributed to the fact that considerable light was absorbed by the globe cap at the beginning of the test, and that as the arc lamp burned further down in the globe, there was less absorption from this cause.

While I have not had an opportunity of reading the paper carefully, I recognize the table of data on arc lamps as I had looked over a similar one several months ago. I believe it is approximately correct, at least as near as such figures can be obtained and relied upon. Some of this data was taken from tests made in the laboratory of the General Electric Company in Schenectady, although the figures on the miniature four-ampere lamp, which is the first one given, were not from that source. Most of the curves given in the paper were evidently made in the Schenectady laboratory, and as Mr. Rose, who has charge of this work under the direction of Mr. W. D'A Ryan is here, I believe it would be in order for him to give the requested information as to how the tests were made.

Now a few words in regard to the broad subject of the paper; namely, the "Comparison of Illuminants." Mr. Ashe's treatment gives, of course, the quantitative or numerical comparison. Such a comparison is necessary and useful, and I believe that we are indebted to anyone who furnishes actual definite figures. I would like to call attention, especially of those who are not particularly familiar with such comparisons, to the fact that a numerical comparison does not tell the whole story, and should not be relied upon entirely in a particular problem. As Mr. Ashe has pointed out, the measure of total light flux does not necessarily show even the quantitative value of an illuminant in a particular installation, although it does give a measure of its value as a light producer. For the quantitative comparison, in

a particular case, I personally favor the use of the lumen, so indicated as to show not only the quantity of light, but also how and where it is distributed. In such a case, the lamp should be provided with the most suitable globe and reflector equipment for the particular conditions, and should be located at a suitable height and spacing. As an extreme illustration one may conceive of a search light being pointed directly downward. While it might provide a considerable flux of light and make a splendid showing, especially in mean hemispherical candle-power, it would be practically useless for ordinary purposes.

That there are other important factors of illumination, besides those of quantity, which should be considered in making the selection for a particular installation; for example, the diffusion of light and reduction of glare. These qualities are frequently obtained to advantage at a sacrifice in quantity. A pleasing and useful color quality of light is also desirable and may be the determining factor in such a selection.

Mr. V. R. Lansingh (Communicated) :—An erroneous conclusion might be drawn from Mr. Ashe's paper if a comparison were made between tungsten lamps and gas lamps. The tests given on tungsten lamps were apparently made in the laboratory, where the fluctuation in voltage could be eliminated and conditions were ideal. Those given, however, in the case of the gas lamps were made under actual service conditions. In the case of street lighting, this covers not only the actual deterioration of the mantle, effect of variation of pressure, etc., but also the absorption of the glass of a lantern, dust on the same, etc., which would very materially alter conditions. In the case of the tests quoted from Mr. Macbeth, it should be noted that the lamps were equipped with reflectors or with globes, which would naturally affect the results.

I wish to call attention to the foregoing paragraph, as otherwise there might be a tendency to draw direct comparisons between laboratory tests and actual installation tests, which of course are not directly comparable, as the tungsten lamp would also show a deterioration with voltage fluctuations, loss due to dirt, etc., in a manner similar to that of the gas lamps referred to.

Mr. S. G. Rhodes :—I want to say a word about the life of the electrode. I think it should be stated plainly that the life speci-

fied is not the usual life, but the life under laboratory conditions, almost a theoretical life.

Mr. L. J. Lewinson:—Mr. Ashe's paper has been assailed by so many this evening that he may welcome a comment upholding his statement that a conservative value of the average candle-power of a tungsten lamp during the first 1,000 hours may be taken as 94 per cent. of the initial value. Lamps of smaller sizes, the 25-watt size in particular, manifest a rate of candle-power deterioration considerably lower than the 60- and 100-watt lamps, so that in 25-watt lamps the average candle-power throughout the first thousand hours of burning may be as high as 97 or 98 per cent. of the initial candle-power.

DISCUSSION BY THE NEW ENGLAND SECTION.

Mr. J. W. Cowles:—The point raised by Mr. Ashe's paper in the suggestion that comparison of illuminants be made on the basis of average rather than initial candle-power performance seems to be so appropriate as to cause wonder why the question has not arisen before. The difficulties attending photometric work, particularly in field measurements, in obtaining comparable results, due largely to the many variable factors which are likely to enter into the investigation, are readily appreciated. Arc lamps, for instance, are endowed with an unusual number of variables and it is therefore not at all easy to obtain results comparable with other results secured at another time either on the same or on a different set of lamps. Special efforts, therefore, are necessary if one wishes not to deceive himself or others by such comparisons.

In the candle-power tests which are being continually made on the Boston street lamps it has been found absolutely necessary to eliminate to the fullest possible extent, the variable factors which make so difficult a correct interpretation of the results obtained. It is very evident therefore, that any suggestion which will make for greater reliability in comparisons between either the same or different illuminants should receive careful consideration; and, clearly, results must vary greatly according as they may be based upon initial or average performance of the illuminants, particularly in those cases where there is known to be a wide variation in the natural performance of the lamp.

It seems to me that this suggestion is perhaps better adapted to technical than to commercial considerations, and I am not quite sure as to how far it might be practicable in such commercial matters as street lighting contracts, etc. It is well known that in dealing with "city fathers" it is necessary or at least it is desirable to be as explicit as possible and that technical terms and phrases are as a rule to be avoided and in endorsing the suggestion at this moment, I have particularly in mind technical rather than commercial dealings. As a matter of fact, one really works along the line suggested by Prof. Ashe since he never thinks of going out on to the street and measuring an individual lamp of any type but expects rather to test enough lamps to insure a fair average in the results obtained, knowing that it is unavoidably possible to pick out individual lamps either appreciably higher or lower than the general average.

In referring to the tabulated data on arc lamps, my interest naturally centers on the figures shown for the two types of Boston lamps, namely, the direct-current series vertical carbon flame lamp and the direct-current series luminous or magnetite lamp. It is gratifying to note that the best efficiency figures shown on the basis of either spherical or hemispherical candle-power are for the Boston flame lamp, as I do not see any figures better than 0.42 and 0.25 watts per candle respectively. I might say that the candle-power figure given, namely 2350, is conservative, and from a knowledge of many tests made in Boston, I have no hesitancy in saying that the figures might have been set quite a little higher. I note that the magnetite lamp results are based upon 11/16 in. electrodes instead of 9/16 in. as used in Boston with appreciably higher candle-power, although this difference is offset by the fact that the tabulated data are based on clear outer globes instead of alabaster as in the cases I have in mind.

Mr. Ashe:—Mr. Cowles has given some interesting information on the operation of arc lamps in Boston, which differs slightly from the data given in the table; and this information will therefore, be valuable as indicating the difference between service and laboratory performance of arc lamps.

Mr. R. C. Ware:—Professor Ashe has brought out a number of interesting points in his paper, and has given a good deal of

valuable information. I do not agree with him, however, in a number of instances.

In the case of the life and efficiency of mantle burners, recent improvements in manufacture have resulted in the production on a commercial scale of mantles of high grade at reasonable cost, which show, I believe, a useful life of 1,000 hours or more, with a maximum decrease in candle-power of about 10 per cent. It is probable that still more satisfactory results shall be obtained in the near future. Prof. Ashe mentions much greater decreases. A good mantle to suffer any serious decrease in efficiency would have to be kept either under very bad maintenance conditions, or for a life in excess of that which is good practice. The gas industry does not believe in keeping a mantle in service after it has reached the familiar "smashing point." It is not unreasonable, therefore, to expect to attain in practice an average efficiency of 90 per cent. or over, with properly equipped and maintained lamps.

Prof. Ashe shows four curves of pilot lights and three tables of consumption. The inclusion in the tables and curves of the performance of what he has termed "the Welsbach turn-down burner," is erroneous as applied to the class of pilot lights. This arrangement is a convenience purely, which is seldom used and never for any length of time. It has been entirely superseded by the use of properly installed and adjusted pilot lights. It is not an economical means of keeping the burner lighted.

Prof. Ashe includes the curve of the Welsbach Junior pilot, which shows a low consumption of about 1/12 of a cu. ft. per hour, which is good standard practice. He has not, however, included the figures in the numerical tables printed. The reflex pilot which he quotes seems to have been adjusted at too great a rate of consumption, the claim as quoted being longer than is good practice. Pilot lights are supposed to be adjusted by the fitter who installs the light, to suit the conditions of the particular location in which the lamp is installed. It is not, therefore, in any way correct to take a lamp fitted with a pilot as supplied from stock, and test its pilot consumption, as it is not, nor is it intended to be, then adjusted for final use.

Prof. Ashe has quoted from some installations reported by Mr. Macbeth, and deducts from the figures published an efficiency

of only 70 per cent. for the gas lamp installation. This deduction is, I should judge, not in any way warranted by the circumstances. Mr. Macbeth gave in the paper referred to a purely general description of the installations in question, which treated only vaguely the actual layout. The color scheme is not described particularly, but from the few words given, it is apparent that it was such as to be fairly high in light absorption. The number and size of windows in proportion to the wall space is not given. The number of projections and pillars, if any, which should cause shadows and interference with general illumination; and the number of empty shelves and the color of shelving, which together would play an important part in the absorption of light, are not given. The amount of light lost through open doors and store window fronts is not specified. I judge from the figures that Prof. Ashe has applied the data given in the Welsbach Gas Salesman's Hand Book to the cases quoted, using the coefficient for light walls, and that he has assumed that Mr. Macbeth's probably limited number of measurements of illumination produced, fairly represent the average illumination throughout the rooms.

In view of the points enumerated above, it is manifestly not safe to figure a percentage of efficiency from the data given, without making a large allowance for the unknown sources of error referred to. Furthermore, I feel perfectly safe in assuming that the best of tungsten lamps which Prof Ashe places at the head of the list would, under similar circumstances, give equally low results, if figured in the same manner. Finally, it is plain that the modern gas mantle lighting equipment deserves a place much higher in the list of efficiencies than that given by Prof. Ashe, and that under present standard conditions of good gas practice, the efficiency for useful life should be well over 90 per cent.

Mr. J. S. Codman:—The most interesting part in the paper perhaps is the comparison of lamps on the basis of average candle-power performance throughout life. This manner of comparison is, I believe, correct in principle, but somewhat difficult to carry out in practice. In the first place, it is necessary to define what is considered to be the life of each lamp compared.

For example, on page 517 the average candle-power of the tungsten lamp is given as 94 per cent. of the initial candle-power and the life of the lamp is given as 1,000 hours. In practice, however, the lamp might burn longer, in consequence of which the average candle-power would be less. On the other hand breakage might shorten the life, in which case the average candle-power would be higher. On page 505 it will be observed that the life of the lamp in these tests was from 1,800 to 2,000 hours and the average candle-power and per cent. of the initial was about 87. For the mercury-vapor lamp the values given on page 517 are 75 and 61 per cent.; the latter for the direct-current lamp. The test on which this last figure is based is referred to on page 516 and the life is there given as 839 hours. As the actual life of the mercury-vapor lamp, however, is considerably greater than 839 hours, running up to 4,000 hours or more, it would seem that the average candle-power throughout life in practice would be less than the value given. However, it will be noted from figure 8, page 511, that the curve runs almost horizontally, beginning at 800 hours. Therefore, the reduction in the average figure would not be very great. It should be borne in mind, however, that this was a test of only one lamp and is not, therefore, very conclusive. The manufacturers claim a much higher value.

The value for gas mantles on page 517 is 70 per cent. and this is based on various tests referred to on pages 506 and 507. In this connection I do not think the Chicago test referred to on page 506 nor the test of Dr. Bell referred to on page 507 are of much value as a number of factors entered these tests which were not considered in the test of tungsten and mercury-vapor lamps. These two tests were on street gas lamps and the maintenance of these lamps was very poor and, further, they were not cleaned before being tested. I assume that the figures for the tungsten and mercury-vapor lamps were with clean bulbs and tubes.

The tests of the consumption of pilot flames are very interesting and show much higher values than are ordinarily admitted by the manufacturers. On the basis of these figures the consumption of the pilot flame is of considerable importance. If, for example, it be assumed that the reflex burner consumes in the pilot 0.15 cubic foot per hour and operates throughout the

year, that is 8,760 hours, the total consumption will be 1,314 cubic feet. If it be assumed that the burner itself consumes 3.5 cubic feet per hour and operates for 1,000 hours per year, the consumption of the burner will be 3,500 cubic feet. From the above statements it follows that the pilot adds in this case more than one-third to the consumption of the burner.

At the top of page 510 Mr. Ashe states that in the case of mercury-vapor lamps a distance of 20 feet from the lamp to the photometer screen is sufficient to justify the assumption of a point source. It is my understanding that the manufacturers claim that the above-mentioned distance should be ten times the length of the light giving portion of the tube. The distance of 21.25 feet, which is the distance used by Mr. Ashe, is somewhat smaller than this. Therefore, as I understand it, the candle-power results are not quite as high as they would be if a greater distance had been taken.

I note on page 510 that the author states that the mean spherical candle-power should be determined in three planes, but he does not state what these planes should be. It would seem to me that if the candle-power is determined in a vertical plane at right angles to the tube and then multiplied by the reduction factor of 78.54, the final results should be practically correct.

Mr. Ashe (Communicated in reply) :—Mr. Codman states that he sees no reason why the mean horizontal candle-power value of a mercury-vapor lamp should not be measured, the reduction factor employed and the total luminous flux determined. This is a good suggestion. In fact, the reduction factors were given in the paper so that this method could be used for quick work. Where the tube is equipped with a reflector, however, it is desirable to obtain its distribution curve, in case one should desire to obtain the luminous flux in various zones. For this reason some photometric method for obtaining these values is necessary, which prompted the author to mention photometering the tube in three planes. As to what these planes should be, one should be perpendicular to the tube, the other plane passed through the tube, and the third should be 45 degrees.

Mr. Codman has also called attention to the fact that in taking the value of the reflex pilot flame consumption as given in

the paper (assuming an inverted lamp operating under normal conditions, where the lamp itself would operate about three hours a day, and the pilot flame 24 hours a day) the pilot gas consumption would be about thirty per cent. of the total. It is realized, therefore, how important is this item of pilot flame consumption. It was this reason which prompted the author to make the tests to determine actual values. It might be mentioned incidentally that this value of the reflex lamp checks fairly well with tests of the 150 pilot tubes mentioned in the recent paper of the National Electric Light Association by Mr. Gille.

TRANSACTIONS OF THE

Illuminating Engineering Society

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COUNCIL NOTES.

The council met for the first time this season in the general office of the society, 29 West Thirty-ninth Street, New York, October 13th. Those in attendance were A. E. Kennelly, president; Herbert E. Ives, A. S. McAllister, W. H. Gartley, George Ross Green, L. B. Marks, V. R. Lansingh, treasurer; E. P. Hyde, G. S. Barrows, James T. Maxwell and Preston S. Millar, general secretary. Past-president C. H. Sharp was present upon invitation.

After the minutes of the June meeting had been adopted, Mr. Millar presented a report of the business that had been transacted by the executive committee since the June council meeting. The report stated that the committee had approved the payment of vouchers aggregating $1,095.01, elected to membership in the society twenty-one applicants, and approved the 1911 convention arrangements as outlined by the convention committee.

The status of the society's finances and its membership was set forth in a monthly report presented by the assistant secretary. The expenses for the first nine months of 1911, according to the report, totaled $6,315.65. That amount was made up of the following items: Transactions $2,605.10, general office $2,302.83, New York section $385.03, Philadelphia section $124.34, Chicago section $234.43, miscellaneous $598.61. An estimate of the probable expenses under each of the latter accounts for the balance of the year was subjoined to the statement of expenses. According to this estimate a deficit of more than $500 will be incurred for the year.

The statement of the society's membership showed that since the first of January 133 members had been elected and reinstated. During the same period 84 names had been dropped from the

roll of the society on account of resignation and death. The net gain in membership was 33 members. The total membership October 1st was 1,501 members.

Resignations from twenty-five members were presented. Twelve of the resignations were accepted; while the names of the other thirteen members were dropped from the society's roll for default of 1911 dues. The names of two deceased members, Lemuel R. Hopton and Nathaniel A. Dutton, were also dropped.

Forty applicants for membership in the society were elected. One application for reinstatement was accepted.

Counting the above-mentioned additions and defections the present membership of the society totals 1,515 members.

Mr. Marks, chairman of the finance committee, presented a report which included the approval of his committee of vouchers aggregating $1,227.22. The payment of the vouchers was authorized by the council.

Mr. Lansingh, chairman of the advertising committee, reported on the work of his committee for the past year. He said that the earnings from advertising had amounted to $869.86.

The following committee on reciprocal relations with other societies was appointed: Dr. H. E. Ives, chairman; Dr. Louis Bell, Mr. L. B. Marks and Mr. J. R. Cravath. It was understood that other members of that committee would be appointed later.

Dr. Ives, on behalf of the members of the Chicago section, proposed two amendments to the constitution of the society. These proposals were referred to the committee on constitution revision.

Certain proposals for constitution revision were submitted by the committee on constitution revision and were approved. These proposed amendments, after they have received the endorsements of the requisite number of members, will be submitted to the vote of the membership at the next election of officers.

Mr. L. B. Marks was appointed chairman of a committee to prepare a primer embodying the elementary principles of good illumination. The committee will be known as the committee

on illumination primer. Dr. Louis Bell and Mr. J. R. Cravath were appointed members of the committee.

The following notice is printed here in accordance with a resolution of the council:

Authors of papers which have appeared in the TRANSACTIONS since February, 1911, when the giving of fifty reprints of papers gratis to authors was discontinued, may upon application to the general office obtain reprints of their papers at the usual price. Hereafter authors of papers will be informed, when the proofs of the papers are submitted for their approval, of the prices of reprints while the papers are in type. The price for such reprints will be nominal.

SECTION MEETINGS.

CHICAGO SECTION.

The first meeting of the Chicago section this season was held in Savage Club room of the Kuntz Remmler Restaurant Company, Thursday evening, October 19. Before the meeting there was an informal dinner. Dr. Herbert E. Ives delivered an illustrated lecture entitled, "Random Notes on Light and Life in Europe." Dr. Ives' lecture referred particularly to the illumination of many ancient and historic buildings and streets in Greece, Italy, Germany, France and England. He also touched upon some of the present lighting conditions in those countries. To say the least, the lecture was enthusiastically received and proved to be very instructive.

The next meeting of the section will be held Thursday, November 16. A paper entitled, "Theatrical Illumination," will be presented by Messrs. F. A. Vaughn and G. H. Cook. The meeting place has not yet been decided upon.

The officers of the Chicago section for the season of 1911-1912 are: chairman, R. F. Schuchardt; secretary, A. L. Eustace, 105 North Wabash Avenue, Chicago; managers, C. A. Luther, and A. J. Morgan.

NEW YORK SECTION.

The New York section held its first meeting of the present season in the United Engineering Societies' Building, 29 West

Thirty-ninth Street, October 12. The meeting was devoted to a discussion of several papers which had been presented at the convention of the society in September.

Next month's meeting will be held Thursday evening, November 9, at the usual meting place, United Engineering Societies' Building. Mr. F. G. Hancock of the General Electric Company will read a paper entitled "Publicity Work Pertaining to Illuminating Engineering."

Mr. Albert J. Marshall, who has for a third time been elected secretary of the New York section, will be pleased at any time to communicate with any member of the society pertaining to the affairs of the section. His address is 16 East Fortieth Street, New York.

NEW ENGLAND SECTION.

The New England section management is arranging for a number of excellent papers to be presented before that section throughout the season 1911-1912. The first of these will be presented at the meeting to be held Monday evening, November 13.

The officers of the New England section for the ensuing season are: chairman, Prof. H. E. Clifford, Harvard University, Cambridge, Mass.; secretary, H. C. Jones, 10 High Street, Boston, Mass.; managers, W. S. Farrow and J. S. Codman.

PHILADELPHIA SECTION.

The Philadelphia section began its season of 1911-1912 with an unusually successful meeting October 20. Prof. S. W. Ashe of the General Electric Company, Harrison, N. J., presented a very interesting paper entitled, "Training of Commercial Men in the Fundamentals of Illumination." Following the discussion of Prof. Ashe's paper a series of stereopticon views exhibiting the manufacture of a Welsbach mantle from beginning to end was shown. In the way of amusement, there was a demonstration of the electrically operated gramophone by the Columbia Phonograph Company. There were 110 members and 58 visitors present. At the informal dinner which preceded the meeting about 50 members were present.

The next meeting of the section will be held November 17.

The officers of the Philadelphia section for the season 1911-1912 are: chairman, Joseph D. Israel; secretary, L. B. Eich-

engreen, N. W. Cor. Broad and Arch Streets, Philadelphia; managers, Prof. A. J. Rowland and C. W. Wardell.

OBITUARY.

NATHANIEL A. DUTTON.

Mr. Nathaniel A. Dutton, sales manager of Edward Miller & Company, manufacturers of lighting fixtures, died suddenly in Meriden, Conn., August 17, 1911. He was about fifty-five years old and had been widely known in the lighting fixture and glass industries. Mr. Dutton had been affiliated with the Philadelphia section of the society and had taken an active interest in its affairs.

LEMUEL R. HOPTON.

In the death of Mr. Lemuel Robert Hopton on September 5, the Illuminating Engineering Society lost a member who had done much toward advancing the science and art of illuminating engineering. Mr. Hopton was a frequent contributor to the literature on illuminating engineering in the technical press and the Transactions of the society. He was one of the pioneers of the society and during the past season was one of the managers of the New York section.

Mr. Hopton was born June 20, 1873, at West Stratford, Conn. He was graduated from the Scheffield Scientific School of Yale University with the degree of Ph. B. in 1896. Two years later he received the degree of M. E. from the same institution. Subsequently he became superintendent of the Enos Company, manufacturers of lighting fixtures, in New York. In that position he devoted his attention ostensibly to the design of lighting fixtures and accessories and the acquirement of a wide and scientific knowledge of the problems of illumination. During his connection with the latter company he invented several useful devices for fixtures and lighting apparatus. To him is due also much of the credit for the development the reflector which is known in trade by the name Opalux. Soon after the inception of the society the Enos Company created for him the title illuminating engineer in recognition of his meritorious work—which, inci-

dentally, was one of the first acts of recognition of the profession of illuminating engineering by a commercial organization.

Mr. Hopton's praiseworthy work, like his congenial and sincere manner, will long be remembered by his friends and associates.

THE FIFTH ANNUAL CONVENTION.

The fifth annual convention of the society was held in the Florentine room of the Congress Hotel, Chicago, September 25 to 28. There were six sessions in all at which fifteen papers and three reports, besides the president's address, were presented. The discussion of papers and reports was spirited and interesting. The entertainment features were pleasing. Two hundred and fifty-four names were recorded on the registration list—142 members, 17 ladies and 95 visitors. Such is a summarized account of the convention.

In the absence of President Kennelly, Mr. V. R. Lansingh, senior vice-president called the convention to order at eleven A. M., September 25. The chairman then introduced Mr. John F. Gilchrist who made a brief and appropriate address of welcome. The response to Mr. Gilchrist was made by Mr. Joseph Israel of Philadelphia.

President Kennelly's address, "The Relations of Physico-Physiological Research to Illuminating Engineering" was read by Vice-president Lansingh. The address was received with not a little enthusiasm. After a brief discussion it was referred to a committee of three for deliberation.

The rest of the first session was given over to the presentation and discussion of the reports of the committee on nomenclature and standards (sub-committee on photometric units) and the committee on progress. Both reports with their attending discussion appear in this issue of the TRANSACTIONS.

The remaining five sessions were devoted to the presentation and discussion of the following program of papers:

"The Manufacture of Glass for Illuminating Purposes." By E. H. Bostock.

"Symposium on Illuminating Glassware." By Messrs. G. H. McCormack, A. J. Marshall and L. W. Young.

"An Analysis of the Requirements of Modern Reflector Design." By F. L. Godinez.

"Natural Gas, Its Production and Utilization." By George S. Barrows.

"Recent Small Gas Lighting Units." By F. H. Gilpin.

"Recent Developments in the Manufacture of Incandescent Lamps." By J. E. Randall.

"The Analysis of Performance and Cost Data in Illuminating Engineering." By Ward Harrison and G. H. Magdsick.

"The Evaluation of Lamp Life." By Preston S. Millar and L. J. Lewinson.

"The Photometry of Large Light Sources." By G. H. Stickney and S. L. E. Rose.

"Photometry at Low Intensities." By Dr. Louis Bell.

"The Effectiveness of Light as Influenced by Systems and Surroundings." By J. R. Cravath.

"The Distribution of Luminosity in Nature." By Dr. H. E. Ives and M. Luckiesh.

"The Law of Conservation as Applied to Illumination Calculations." By Dr. A. S. McAllister.

"Resume of Legislative Enactments on Illumination." By E. L. Elliott.

"Illumination or Equipment?" By F. B. Rae, Jr.

Six of these papers and their attending discussions appear in this issue of the TRANSACTIONS; the remaining papers will appear in the November number.

In the way of diversion there was a reception and dance in Florentine room of the Congress Hotel, Monday evening, September 25. In the same room there was a banquet on the evening of September 27. Both events were well attended by members and their guests. For the ladies there were two automobile rides, September 25 and 26, to places of interest in and about Chicago. Tuesday afternoon, September 26, the members were

taken in automobiles on several inspection trips. The places visited were the power station of the Commonwealth Edison Company at Fisk and Quarry Streets, the Peoples Gas Building, demonstration rooms of the National X-Ray Reflector Company, the plant of the Sears, Roebuck & Company, and the laboratories of the Armour Institute of Technology. Wednesday afternoon there was a theatre party for the visiting ladies.

The attendance and registration figures of the convention are especially interesting. The 142 members registered were from 41 cities throughout the country. The average attendance at each session was 144 people. The latter figure includes an average of 8 visitors. In other words practically every member who registered was present at all six sessions of the convention. In this respect at least the 1911 convention was unique.

It will appear trite to have the fifth annual convention recorded as "the most successful ever held" by the society—certainly that expression has been written down elsewhere more than once—yet for want of more accurate comment it has been put down again. As conventions go the fifth annual convention of the Illuminating Engineering Society was unusually successful.

ERRATUM.

In the June number of the TRANSACTIONS, page 555, 46.20, the last figure in the last column, should be 64.20.

THE RELATIONS OF PHYSICO-PHYSIOLOGICAL RESEARCH TO ILLUMINATING ENGINEERING.[1]

BY A. E. KENNELLY.

I greatly regret that owing to engagements of long standing, in connection with the International Electrical Congress in Turin, I shall have to be distant from Chicago about one hundred degrees of longitude on the day of the convention of the Illuminating Engineering Society, a convention I should otherwise have taken much pleasure in attending.

In my first inaugural address, on "The Profession of Illuminating Engineering," printed in the February number of the TRANSACTIONS, I endeavored to show how numerous and varied were the fields for activity and research within the immediate purview of this society. In this second inaugural address, I desire to submit for consideration the importance of activity and research in a single field, out of the many that the society has in its keeping. It is not that this particular field, to be considered, is necessarily more important, or more urgently to be explored than any or all of the rest; but merely that it is illustrative. Probably at least as good a claim for consideration might be made on behalf of any of the others in turn. The intention here is to indicate the closeness of the connection between apprehension and accomplishment in a single direction of the science and art of Illuminating Engineering—the measurement of light.

Every department of natural science takes its origin in a collection of scattered collated observations. At first, these may seem disconnected, and at variance. In the earlier stages of any science, there is a constant increase in the number and complexity of the observations, with little or no gain in their perspective, or in the apprehension of their mutual relations. After the science has reached a certain stage of development, depending upon its extensiveness, the relations of the various observations to each other become apparent, as parts of definite phenomena. The observations still increase in number and complexity;

[1] Presidential address, fifth annual convention Illuminating Engineering Society, Chicago, Sept. 25-28, 1911.

but they arrange themselves into coördinate groups, so that the process of observation-accumulation comes to mean, by condensation, a process of fact-accumulation. After the science has reached the next more advanced stage of development, it is found that the various phenomena are related in a definite and apparently unvarying manner; either in relation to each other, or to phenomena in other sciences. This is the stage of discovery of qualities of law, or causal relation. At this stage, a great change appears in the psychological aspect of the science. Whereas the observations and their phenomenon-groups had previously been scattered incoördinately, over the whole field of thought, nucleation now commences everywhere, and the field begins to change from an amorphous to a structural aspect. At a still later stage of development of the science, it is found that these laws are prescribed by definite quantitative relations. This is the stage of the introduction of arithmetic, or exactness, to the science. The highest development of a science known to us is that in which all the laws are recognized and are exceedingly simple, so that they may be reduced to the operations of simple arithmetic. Every observation becomes associated with its proper phenomenon. Every phenomenon becomes connected with its proper law. Every law becomes amenable to simple arithmetic. In this aspect, all proper development in the natural sciences is from the inchoate to the structural, from the complex and manifold to the simple and unique, from the difficult to the easy. When we acknowledge that a science is very difficult to understand, we admit that it is undeveloped. When we say that the higher mathematics are needed in order to grasp it, we are saying, in effect, that its relations are not yet fully perceived. All nature, as we gradually come to realize it, is one, and is simple. This is no disparagement to higher mathematics, or to recondite studies, but rather an implied encomium, because a science has to be difficult before it can become easy.

All the natural sciences aim, then, at becoming exact sciences, and become exact through the making, correlation, and reduction of measurements. Any branch of natural science without measurements is not above the qualitative stage. The number and degree of precision of the measurements in a branch of

science is a gage of the extent to which that branch has become exact.

The measurements connected with the quantitative sciences, on which illuminating engineering depends, are mainly photometric measurements. These are, in turn, limited, with few exceptions, to the measurement of illumination. Either two illuminations, or two illumination-contrasts, are presented, side by side, to the observer's eye, with means of adjusting their relative intensity. This is another way of saying that adjacent definite areas of the retina in the observer's eye are brought into comparative stimulus by the illuminations examined, and the observer exerts his judgment to decide when the two sets of stimulus-impressions have equal intensity.

Not only is the precision with which such a judgment can be made relatively small, but the precision with which our standard illumination can be independently re-duplicated is also relatively small. Our flame standards are so inferior, in this respect, that they have virtually been abandoned in the maintenance of the international candle, in favor of a group of incandescent lamps. If these lamps should all be destroyed simultaneously, the standard could not be reproduced to a degree of precision nearly as great as that with which it can be copied photometrically.

It is well understood that ordinary light is, subjectively, the sensation produced by radiant power, which, in its turn, is the power of alternating electric waves in space within a certain range of frequencies, representing about one octave, and lying between the approximate limits of 400 and 800 millions of millions per second. When such alternating-current power, or rate of transfer of energy, exists at a given position in space, an observer placing his eye so as to intercept it will receive the impression of light, provided that the power-density, in watts per normal square-centimeter, is not less than a certain small threshhold value, at which the stimulus begins to be perceived, on the one hand: nor more than a certain much larger value, at which on the other hand, the stimulus is excessive and dangerously great. The values of these power-density limits are, as yet, only very imperfectly known, for even a single frequency.

It is also known that the sensation of light, or the candle-

lumens per unit of radiant power-density is very different for different frequencies of electric alternation. If, to avoid periphrasis, we call the unit of radiant power-density (one watt uniformly and perpendicularly passing through one square centimeter) one area-watt, then one area-watt received by the eye will give rise to the sensation of more light in the yellow-green frequency than at either end of the spectrum. The lumens per area-watt are known to be greatest at or near the frequency which is most prominent in daylight. But when the radiant power-density is feeble, and the candle-power perceived is low, the lumens per area-watt are known to be greatest at a somewhat different frequency; so that the relative sensibility of the eye to stimulus, at different frequencies, varies with the intensity of the stimulus. In all of these particulars, a good start has been made towards quantitative knowledge, and the literature of the subject is already large; but far more remains to be investigated before our knowledge can be regarded as satisfactory along any of these lines. We ought to know the lumens per area-watt produced in the normal eye for each color, and its frequency, as well as for all working intensities. Beyond this, there remains to be found how far the norm is departed from in the eyes of different ages and races of men, as well as the effects of attention, of training, and of physiological fatigue. We can never know the lumens per area-watt at any frequency, or intensity of radiant power-density, for the normal eyes of races that have passed. It is beyond our hope to know how the sensibility to radiant power-stimulus of the average normal eye may have changed from the days of Rameses I down to the present; but at least, it lies open to hope to make records that will permit of such comparisons being made from the present into the future.

Specifically, it has been proposed by Dr. Steinmetz[1] to produce white light of measured power-density by the artificial combination of three, and only three, measured colors of light, and so to arrive at a more precise knowledge of the lumens per area-watt of definite radiation power-density. Dr. Ives[2] has also proposed that the measurement of lumens per area-watt should be

[1] Trans. A. I. E. E., July, 1908.

[2] Trans. I. E. S., "Energy Standards of Luminous Intensity," vol. 6, p. 258.

made with light of the particular frequency to which the eye is most sensitive in fairly powerful illumination. We certainly need the sensation-value of radiant power-density for white light and for the most stimulating color of light; but it would seem that the first measurements are more likely to be made with satisfactory precision at single definite frequencies, or colors, than at any particular combination of them, such as white light requires.

Assuming that we possessed a proper knowledge of the lumens per area-watt, for all the different colors and frequencies of light, at all working intensities, it would become possible to make a spectro-photometrical examination of the light from any lamp, say a Welsbach mantle burner, then average the lumens per area-watt over the whole of its spectrum, to measure the total radiant power of the burner in watts, and then express the radiation-density watts per lumen in a significant manner. At the present time, the expression "watts per candle" refers, in the case of a gas lamp, to the total fuel-consumption power per candle, and in the case of an electric lamp, to the total power-consumption per candle at lamp terminals, quantities which are in themselves important, but which are of very different signification from those under consideration.

Moreover, assuming that we had a satisfactory knowledge of the sensation-effect of radiant power-density, it would be valuable to know the sensation-effect of radiant energy-density. That is, if a certain quantity of electro-magnetic energy, uniformly and perpendicularly flowing through each square centimeter of area, were intercepted by the pupil of an observer's eye, what would be the sensation effect? This could be found by permitting radiant power of known quality and density to fall on the eye for a measured brief interval of time, as by means of a falling camera-shutter.

All research connected with photometry borders, on the work of ocular physiology, and of psychology. Consequently, all such research, in order to be most effective, should be undertaken with adequate information concerning what has already been accomplished in those sciences along similar lines.

Since it has probably taken millions of years to develop the

human eye from the first patch of somewhat radiantly-sensitive skin of a remote and primitive progenitor, it is not wonderful that the study of the eye should be so difficult. On the contrary, is it not wonderful, rather, that from a broad optical standpoint, the physical mechanism of the eye should be so easy to comprehend?

It might at first thought be supposed that the knowledge, in a few laboratories, of certain physico-physiological constants for the human eye was of no importance to the broad industry of illumination, to its manufacture, engineering, distribution, or sale. Nevertheless, it may well be contended that, on the contrary, all such knowledge is of great importance to the industry in many ways. In the first place, disputes tend to vanish when the matters in dispute are properly known to a specially trained few, even though the facts may be out of the line of vision of the many. Secondly, all such knowledge rapidly begets applications, improvements, economies, in a manner of which modern experience affords many examples. If only for the utilitarian advantage of such research, this address is offered as a plea for the accumulation of observations on the photometric properties of our eyes, by all who may have the opportunity to make them.

DISCUSSION.

Mr. J. R. Cravath:—Your committee on the president's address begs to submit the following report:

The address of Dr. Kennelly is a scholarly review of the problems and ideals of one line of scientific research upon which illuminating engineering is based. The fundamental measurements of illumination are made through the medium of the eye. They are, therefore, not purely physical, they are in part physiological. With the complete elucidation of the complicated relations between the physical and physiological factors, the determination of illuminations of all qualities and intensities will be a matter of arithmetical calculation from comparatively simple physical measurements. Photometric standards will be placed upon a basis logical instead of arbitrary; the expression of efficiency will be upon a rational scale. It is this ideal toward which

the worker in physico-physiological research is striving. His work may appear to the casual onlooker or to the purely practical man as far removed from immediate or even future utility, but experience has shown that the scientific measurements of one age becomes the practical measurements of the next, that the refinements of the scientist of to-day become the working units of the engineer of tomorrow. So the continually accumulating results of physico-physiological research may be expected to assist and become essential to the science and art of illumination.

In this review Dr. Kennelly has given what should be an inspiration to the worker in such research. He has done a service both to the scientist and to the practical man by emphasizing the bearing of the work of one upon the work of the other.

Your committee cordially recommends this paper to the consideration of all members of the society, and unanimously recommend its printing in the TRANSACTIONS.

J. R. CRAVATH.
W. H. GARTLEY.
HERBERT E. IVES.
Committee.

Dr. E. P. Hyde:—There is one point in Dr. Kennelly's address in which many of us are interested and on which I have heard some discussion since coming to the convention, and it would seem to me that it might not be unwise to add a word or two regarding that one point. Dr. Kennelly's paper is a plea for the accumulation of observations, taking as the illustration physico-physiological measurements. We are in a somewhat unique position. About two years ago Mr. Millar, myself and possibly others, so far as I know, suggested the appointment of a research committee. That committee was not appointed by President Gartley, he very kindly leaving it to the following administration. It is only because I am so ashamed that I failed to appoint the committee myself that I feel I can make Dr. Kennelly a little bit ashamed by saying to him that he has a very ready means of putting into effect his own plea by appointing that committee which is still unappointed. It seems to me

that Dr. Kennelly touches a vital point, and it is a consideration which has been prevalent in the discussions this morning on Mr. Harrison's paper; it goes back to the fundamentals in the conception of the proper functions of the Illuminating Engineering Society. It seems to me that the primary function of the Illuminating Engineering Society is that of accumulating and presenting accurate information not only on economy but on all the other elements which enter in determining illuminating installations; and it seems to me that this goal can be attained very much more readily if we had some committee, such as was contemplated in this research committee, that could undertake to receive suggestions from members or to make suggestions themselves as to necessary and important research along various lines of illuminating engineering. These researches would not be physical only, nor physiological nor psychological; they would cover all phases of illuminating engineering. If the society thought it desirable to undertake such an investigation, that committee should be so constituted that it could supervise an investigation such as was asked for in Mr. Harrison's paper. The research committee should be a clearing house for the accumulation of accurate information. If there was any branch of the science of illuminating engineering that needed further information, if there were any apparent scientific discrepancies or practical discrepancies that needed elucidation, that committee should see, not necessarily undertake the work itself, but should see that research work was undertaken in order to settle those various points. Now, it seems to me that this is something of very practical value and of very great interest, and I thought it might be worth while to pause a moment to emphasize the importance of it. I am a little sanguine that this committee may some day be appointed, and I believe that if Dr. Kennelly reads that this society so heartily approves his plea for further investigation and accumulation of data as to urge him to put into practise his own plea, he will probably appoint the committee promptly.

REPORT OF COMMITTEE ON NOMENCLATURE AND STANDARDS—REPORT OF SUB-COMMITTEE ON PHOTOMETRIC UNITS.[1]

To the Illuminating Engineering Society:

Your committee on nomenclature and standards begs leave to submit the accompanying report of the sub-committee on photometric units as a report of progress.

Respectfully submitted

ALEX. C. HUMPHREYS,

Chairman

REPORT OF SUB-COMMITTEE ON PHOTOMETRIC UNITS.

As instructed by the 1910 convention, the sub-committee on photometric units endeavored to get in touch with foreign authorities on the question of photometric units, with a view to paving the way for future agreement on these questions, taking the progress report of 1910 as a basis. With that in view the chairman of the sub-committee has communicated with the following gentlemen in foreign countries:

Mr. C. C. Paterson, of the National Physical Laboratory, London.

Mr. A. P. Trotter of the Board of Trade Standardizing Laboratory, London.

Prof. Sylvanus P. Thompson, President of the British Illuminating Society, London.

M. F. Laporte, Laboratorie Central d'Electricité, Paris.

Prof. Eric Gerard, Director of the Montefiore Institute, Liège.

Mr. Ormond Higman, Chief Electrical Engineer, Electrical Standards Laboratory, Ottawa.

Replies have been received from Messrs. Gerard, Trotter, Higman and Paterson. Mr. Trotter objects to the designation of the intensity unit as "candle" rather than "candle-power," but otherwise approves of the report. Mr. Higman expresses his sympathy with the work of the committee, but doubts the desirability of using the letters I, E, R, C and L for photometric units inasmuch as they are used to express other physical quan-

[1] A report read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

tities. Mr. Paterson has submitted a number of very valuable suggestions which are at the present time before the committee for its consideration. In addition, M. Blondel, a member of the sub-committee, has undertaken actively to interest scientific bodies in France in the approval of last year's report and has taken up the matter with the French Physical Society and with the Society of Electricians. The sub-committee is greatly indebted to M. Blondel for the work which he has done, and is doing, in this direction.

It will be seen that the progress during the year has been slow, yet some foundation has been laid for future activity, and no rapid progress is to be expected in negotiations of this character. The report of the committee has frequently been referred to in the foreign technical press and has thereby attained considerable publicity abroad.

The committee would make the following recommendations:

That the term "lighting" be used to designate the product of luminous flux by the time, the symbol therefore being "L." The "L" then would displace the "Q" used as a symbol for this quantity in the 1910 report. The committee would further recommend the adoption of the following symbols:

Mean spherical candle-power, $I\ominus$.

Mean upper hemispherical candle-power, $I\overset{\frown}{-}$,

Mean lower hemispherical candle-power, $I\underset{\smile}{-}$.

Total flux, $F\ominus$.

Upper hemispherical flux, $F\overset{\frown}{-}$.

Lower hemispherical flux, $F\underset{\smile}{-}$.

These symbols have been proposed by M. Blondel and differ but slightly from those used in Germany, the bar being carried a little beyond the circle on each side. The idea is that the symbols will be less liable to confusion if this form is adopted.

The committee would further recommend that negotiations with individuals and societies in other lands be carried on with a view to the possibility that eventually this society will arrange for an international conference to bring about an agreement on these subjects.

Respectfully submitted for the sub-committee,

CLAYTON H. SHARP,

Chairman.

DISCUSSION.

Dr. A. S. McAllister:—The difficulties encountered by the committee in selecting symbols for the photometric quantities that will be acceptable to all persons the world over can readily be appreciated by any person who has attempted to find symbols satisfactory even to himself alone. The task is certainly no small one, and the committee is to be encouraged in its efforts; its suggestions should be adopted to the fullest extent possible in so far as the symbols do not conflict with present established usages in related sciences. That the suggestions of the Illuminating Engineering Society's committee have weight with other societies is evidenced by the fact that the symbols proposed by the committee last year have been incorporated as recommendations in the standardization rules of the American Institute of Electrical Engineers published in the August, 1911, *Proceedings*.

As a result of the Illuminating Engineering Society committee's ignoring long established usage of a few of the twenty-six letters of the alphabet as symbols for electrical quantities, the American Institute of Electrical Engineers rules now contain the absurd recommendations of two distinct quantities for each of the frequently used letters E, I and R, long recognized as the symbols for expressing Ohm's law. Thus the electrical engineering writer who would attempt to follow the recommendations fully in formulating the inter-relations between the electrical and lighting characteristics of a lamp would find some of the above three letters appearing twice in a single equation with two distinct physical meanings. This deplorable result could easily have been avoided by selecting some of the twenty-three remaining letters of our alphabet or introducing some of the letters of the Greek alphabet, as has been done, for example, with the letter ϕ (phi) universally recognized as the symbol for magnetic flux.

The chairman of the sub-committee, Dr. Sharp, has shown in a remarkably clear manner the similarity between light flux and magnetic or electrostatic flux. It would seem not to be undesirable, therefore, to recognize this similarity in selecting the symbols for light flux. The present writer is bold enough to state that no more appropriate symbol can be selected for light flux than the Greek ψ (psi). This letter resembles the symbol for mag-

netic flux ϕ (phi) both in appearance and pronunciation; moreover, it is highly suggestive of a three-candle lighting fixture, which fact should meet with the favor of those who wish the symbols to picture the quantity represented. As the symbol for light flux density—the foot-candle, the meter-candle, the lumen or candle per unit area—the Greek letter β (beta; small letter) seems highly appropriate by reason of its similarity to the symbol for magnetic flux density, $\mathscr{B}$ or B.

The use of the pictorial symbol is to be recommended, but sight should not be lost of the fact that when such a symbol involves the manufacture of new type or reconstruction of old type, opposition to the innovation is sure to arise in quarters having much influence, so that the special-type symbol will certainly not be widely adopted and will probably not long be used for the purpose intended. The writer can only express his regrets that the type available in modern printing establishments does not include the spherical and hemispherical signs recommended by the committee.

REPORT OF THE COMMITTEE ON PROGRESS.[1]

To the Illuminating Engineering Society:

The past year has not been marked by any radical innovations either in material or methods. There has been considerable progress in many minor details of the art which your committee will here attempt to notice in brief. The scientific aspects of illumination have not been neglected and the past year has seen both here and abroad researches which give promise of an extension of our knowledge in many directions and of no small practical usefulness.

MATERIALS OF ILLUMINATION.

Arc Lamps:—The chief changes of the year in arc lamp practise have been in the direction of the luminous and flaming types of arc. The magnetite arc, the chief example of the former class, has come into use in largely increased numbers during the past year. The electrodes for these lamps have been, through increasing experience, produced of more uniform and on the whole better quality than previously. The magnetite arcs have in the main replaced the enclosed carbon arcs, chiefly the alternating current arcs of former practise, with a very material improvement in the resulting illumination and, where contracts have been renewed, with a general small reduction of price. It is greatly to be regretted, however, that a petty and pitiful economy has too often permitted the use of the smallest available sizes of magnetite lamps equipped with electrodes in which efficiency has been somewhat subordinated to extraordinarily long life. This is "a penny wise pound foolish" economy which will sooner or later be regretted both by the central station men and the public.

The other variety of luminous arc, that known as the titanium carbide arc, for alternating-current, has to the great regret of illuminating engineers practically dropped out of sight, owing to inherent difficulties in construction and operation for which no wholly satisfactory remedy has yet been devised. The case must not be rated as hopeless, however, and it is heartily to be hoped that a lamp of such high efficiency and so convenient prop-

[1] A report read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

erties may eventually be made thoroughly available. For the present, however, there is nothing to report.

The flaming arcs proper have steadily increased in popularity, especially since of late long burning flame arcs have begun to come into production. The chief fault of the flame arc from the operative standpoint has been the fact that it has practically required trimming every night. This is from the standpoint of the central station manager a nuisance, but would not be so serious as it is save for the high cost of the electrodes themselves which has increased considerably under our late beneficent tariff bill. Between expensive electrodes and frequent trimming the flame arc has been materially handicapped. There have now, however, been made available long burning arcs of three or four American and foreign makes, which raise the burning hours to a point at which trimming ceases to be troublesome and the electrodes being of rather large diameter, although relatively expensive per piece, are themselves cheaper per burning hour even if the specific rate of consumption remains practically the same. Long burning has been attained in these arcs by one or more of the following expedients; increasing the diameter, increasing the length, and changing the composition by the addition of substances which will cause the electrode to burn more slowly. None of these three devices is wholly unobjectionable. The gain in added life merely by increasing the length results in an awkward looking lamp and some of those now upon the market are foredoomed to failure for this reason alone. Increasing the diameter of the electrode tends somewhat to lower the efficiency and injure the steadiness while the addition of any restraining substances to the electrode is extremely likely to injure the efficiency. The best results seem to be obtained by a combination of these various elements so as to use a fairly long electrode of large diameter and of a composition to give as good life as is compatible with high efficiency. The first of these long burning arcs was the well known Jandus, of English manufacture, using a lower electrode of stellate section, the actual material being packed in between the rays, so to speak, of the star. It gave about 75 hours of life at an efficiency not quite as high as the best flaming arcs of the period, but extremely creditable.

Many claims have been made for long burning arcs of other

makes and more recent manufacture. Without examining these things in detail it is within conservative bounds to say that there are now several lamps on the market capable of giving a burning life of at least 75 hours per trim, at an efficiency which, while not quite as good as would be reached by intensive burning of the same electrode, is still from a practical standpoint very satisfactory. It seems somewhat dubious whether the burning life can be increased beyond the point mentioned to any material extent without objectionable loss of efficiency, and the amount of debris produced by the combustion of the long burning electrode is sufficiently great to cause a material reduction of light during the progress of a single trim, unless the globes are cleaned at intermediate periods. The strongest point of these new lamps is that they may be successfully operated on alternating current and give a useful and efficient light of very much higher efficiency than any of the alternating arcs heretofore employed. Discretion must be exercised, however, in the introduction of these lamps lest the continual temptation to attempt to secure longer life lead to so considerable a reduction in efficiency that the usefulness of the lamp may be seriously impaired.

The color of these flame arcs is usually rather a lightish yellow, which your committee does not consider objectionable although the question of color of street illuminants is rather a matter of taste than of science. White flame electrodes to meet the requirements of long burning lamps have not yet been made in this country in commercial quantity and while a highly efficient carbon of this type is manufactured abroad the cost in this country is too high to encourage its use on as large a scale as would otherwise be desirable.

Regarding other arcs the chief point of interest to the illuminating engineer is the increasing use of the small intensive arc lamps burning carbons of one quarter inch diameter or thereabouts, with currents of 5 or 6 amperes. These arcs, at first only capable of burning 18 or 20 hours between trims, have been pushed at a slight loss of efficiency to a burning life of 40 or 50 hours and are highly desirable for certain purposes as giving the closest approximation to white obtainable in any efficient commercial illuminant. For use in dry goods stores, haberdashers shops and the like, these intensive arcs have proved extremely valu-

able and have been rapidly pushed into use during the past year.

Of comparatively new lamps outside the class of ordinary arcs, the most interesting is the quartz mercury arc, commercially introduced for the first time in this country within the last year, although well known abroad. This lamp belongs as regards efficiency in the same class with the flame arcs. It is remarkably steady, particularly as regards any tendency to rapid variations, and the tubes, from foreign reports, give an effective life of one to several thousand hours. The color is much nearer white than the familiar mercury lamp, but is still noticeably lacking in red, although there are several fairly brilliant red lines in the spectrum. It gives promise of usefulness in the lighting of streets and large spaces when it shall be readily obtainable in this country.

Another novelty introduced abroad, unfamiliar in this country, is the Moore tube filled with neon. The nitrogen tube, which has been heretofore described before the society, is already familiar, as well as the CO_2 tube, which gives a remarkably good approximation to white in color although unfortunately at a very low efficiency. The neon tube gives a light of a particularly warm and mellow color and the reports received on it indicate a very much higher efficiency than in any other form of the tube yet devised, the specific consumption being rated at somewhat less than 1 watt per candle. Neon, we may be permitted to remind the society, is one of the gases present in the atmosphere in extremely small quantities and obtainable practically by what amounts to the fractional distillation of liquid air. It is not too troublesome to obtain to render its use at all prohibitive for the purposes of illumination and this innovation is a notable step in the evolution of gaseous illuminants.

Electric Incandescent Lamps:—Coming now to incandescent electric lamps, the most important recent advance has been the commercial introduction of the filament of tungsten actually drawn into wire. The production of this wire lamp is now an accomplished fact and a considerable number of such lamps have been put into use with, on the whole, very satisfactory results. The new filaments are worked at practically the same efficiency as the old, but are considerably more uniform and in

materially less danger of breaking from mechanical shocks. Such lamps may be more safely run in unusual positions than the earlier tungsten lamps and mark a very considerable advance in incandescent practise. In the matter of sizes the tendency in the tungsten lamp manufacture has been upwards. The 400 and 500 watt sizes are now in considerable use. There have been some successful attempts at the production of small tungsten lamps for the ordinary voltages ranging from 15 to 20 watts consumption, but the 25 watt size remains the smallest size considered regular.

The tantalum lamp is still in considerable production in spite of the formidable competition of the tungsten type and is being used in some isolated plants with very good results. It hardly seems possible, however, that it can permanently withstand the inevitable reduction in cost of tungsten lamps of much higher efficiency.

Nothing has been heard recently of any new forms of incandescent lamps. The helion lamp of two or three years ago seems to have dropped entirely out of sight and there are no signs of any present promising efforts along similar lines. Tungsten seems to hold the field as by far the best available material for efficiency in incandescent filaments and as there is no metallic element yet known more refractory than this, incandescent lamp efficiency may be properly judged to have been pushed fairly near to its commercial limit, unless greatly cheapened manufacture permits a somewhat more intensive burning.

Gas Lamps:—Within the last year or two the production of incandescent mantles has undergone considerable improvement, in fact to an extent that the general public does not fully realize. The present mantles of the best class do not give much higher candle-power per cubic foot of gas than previously, but they unquestionably both give a longer life than previously and hold up their candle-power conspicuously better. The ordinary commercial mantle, particularly in its cheaper forms, is still made on a cotton base, but the tendency is very strong toward the use of other material, which gives better life and better average efficiency. Ramie fiber is coming into increasing use as the material for the mantles and from all indications is a considerable improve-

ment over cotton. Still better for most uses seems to be the artificial silk or cellulose mantles now in production, decidedly superior to any others yet produced in the point of maintaining their efficiency with small reduction over a long period. It is interesting to note that the homogenous artificial fiber produced from squirted cellulose is as much superior to natural fiber in the incandescent mantle as it was proved to be years ago in the incandescent electric lamp.

Another material improvement in mantles is the introduction of types containing more ceria than the standard mantles of past years and giving at a slightly reduced efficiency a light free from the somewhat glaring color familiar in the ordinary mantles. In fact one can now obtain mantles of almost any desired hue from a distinctly bluish cast to a mellow orange-yellow.

The high pressure gas lighting common for some years abroad has been tried experimentally in a few places within the past year, but not to an extent which may fairly be called commercial. It is to be hoped that the system will be fairly tried out in this country ere long, although the special distribution system, which foreign experience shows to be necessary for work on a large scale, at present seems to stand in the way of progress.

Gas Lamps and Appliances:—With respect to the actual apparatus for burning gas the inverted Welsbach has been making, during the past year, very rapid progress and is pushing the older upright form toward obsolescence. The inverted lamp lends itself more conveniently to the distribution of light than the older form and is its superior in efficiency, so that the change now inaugurated should be continued until the inverted lamp becomes the regular standard of practise.

Fixtures have been materially improved and in particular shock absorbing devices have been introduced which meet the difficulty heretofore encountered of rapid breaking of mantles in exposed situations.

Methods of lighting gas lamps are being steadily improved. The pressure wave system for street lamp lighting, widely used abroad, has not attained here the same popularity, perhaps chiefly from lack of special mains for street lighting, but it is in very successful use in some cities and as the distribution for street

lighting becomes more specialized this system will find a larger employment. The remarkable pyrophoric alloys of Auer von Welsbach, introduced two or three years ago, have not yet come into general use. The trouble has not been with the alloy but with the difficulties in the mechanical problems. Improvements are now being made, however, and it is believed that this very simple and beautiful method of gas lighting will soon come into larger use.

METHODS OF ILLUMINATION.

The practise of illumination of late has been following quite along the customary lines, the only changes being a gradual evolution toward a somewhat higher degree of lighting and the use of more pleasing, and on the whole better designed, shades and reflectors. The tendency upward in the amount of illumination has been very marked, sometimes indeed passing the bounds of good judgment. During the last year there have been many outdoor installations of a so-called decorative character, and some of them, it is to be regretted, have violated most of the canons of the art. The lavish and reckless use of unscreened arc lamps in display lighting has been on the increase and it is perhaps not going too far to say that, with the best of intentions, the average flamboyant lighting scheme of the last year or two is from the standpoint of the illuminating engineer bad. There is a slight tendency toward the use of diffusing globes for arcs, which deserves to be encouraged; but for the most part extreme brilliancy still seems to be the one thing to be desired in such installations. Some few ornamental installations of tungsten street lamps in diffusing globes are notably good, although not always satisfactory from an economic standpoint. On the streets even display illumination should be designed with due regard for economy, so that a system, once the effect of its newness has worn away, may not be regarded as a financial burden and eventually abandoned.

In indoor lighting the most notable tendency has been toward the use of indirect, and more especially semi-indirect, illumination. Some of the fixtures which have been worked out for the latter scheme are very beautiful in design and yet not uneconomical as is commonly the case with the pure indirect system with opaque coves or reflectors. Progress in this line deserves to be

encouraged, especially from the decorative standpoint in which it is often superior to either ordinary direct or indirect systems. To meet such requirements a large variety of new glassware for both gas and electricity has been put upon the market. It is now possible to obtain not only prismatic and opal glass reflectors in many varieties of finish but those furnishing color and decorative effects very useful in working out fine installations. The use of colored glassware, and indeed colored lights, offers exceptional opportunities for decorative work, one admirable example of which was described before this society last year.

Reflectors for industrial work have been undergoing steady improvement so that at the present time a much larger variety of thoroughly good metal reflectors is available than could possibly have been found a year ago. Reflectors both of glass and metal have been worked out for even the largest sizes of tungsten lamps, so that every available size can now be equipped with a thoroughly efficient and appropriate reflector either for general lighting or for industrial work. Many of the earlier reflectors were too shallow properly to screen the lamps, but those of more suitable length are now available, and where exceptionally complete screening is desired, standard reflectors are often advantageously used with lamps a size smaller than those for which the reflectors were originally designed.

Suitable devices in the way of sockets and shade holders have been recently made available enabling the position of the lamp in the shade to be varied within limits so as to obtain slight modifications of the distribution or a greater or less amount of screening for the bulb. These minor changes are far more important practically than would appear at first sight and constitute a material improvement in the equipment available for illumination. An interesting auxiliary to lighting with mercury-vapor tubes has appeared in the light-transformer of Dr. Hewitt, which is practically a reflector coated with fluorescent material which receives energy from the tube and transforms it into orange light which so supplements the light from the tube itself as to supply the missing color element, and produce a total light flux approximating white or yellowish white as may be desired.

GENERAL PROGRESS IN ILLUMINATING ENGINEERING.

The past year has seen the results of the labors of this society in the greater public interest in good illumination, in a notably better popular understanding of illuminating matters, and in the importance attached to the work of the illuminating engineer. There has been founded during the past year an American Association for the Conservation of Vision, in which a number of members of this society were charter members and in which they are active. This association with respect to matters of illumination can be counted on to actively reenforce the efforts which have already been made by this society toward the improvement of public and private illumination, and it is gratifying to record that similar activity has been displayed abroad in attention to ocular hygiene and to the improvement of illumination for public industrial purposes. A commission has recently been appointed by the French Minister of the Interior to investigate and report on methods of illumination in their practical bearing on vision and on industrial processes, and your committee brings this report to a close by earnestly recommending that this Society should cooperate with this and other foreign committees and organizations working toward the same end, in order to reach if possible at least an international consensus of opinion that may lead to definite progress all over the world in practical illumination.

Respectfully submitted,

LOUIS BELL,
Chairman, Committee on Progress.

DISCUSSION.

Mr. George S. Barrows:—As a member of the committee on progress, I think that it might be well to elucidate one or two matters here which are spoken of in reference to high pressure gas lighting. The report states, "It is to be hoped that the system will be fairly tried out in this country ere long, although the special distribution system, which its foreign experience shows to be necessary for work on a large scale, at present seems to stand in the way of progress." It is true that where high pressure lighting has been adopted widely, in Germany and in

England, special distribution systems have been installed but it is only where there has been a wide application of this system that these special distribution systems have been installed. When high pressure lighting is first started over there in most places, small individual compression plants are put into service, and it is only when the business develops to such an extent that it is more economical to put in one high pressure distribution system and do away with the individual systems that the special system is put into use. In this country two of the installations that I am familiar with are operated by small individual compression plants, while one system is taken from a high pressure pumping main.

Further on the report states in reference to the pressure wave ignition system: "The pressure wave system for street lamp lighting, widely used abroad, has not attained here the same popularity, perhaps chiefly from lack of special mains for street lighting, but it is in very successful use in some cities and as the distribution for street lighting becomes more specialized this system will find a larger employment." It is not at all necessary to use special mains for street lighting, and in none of the installations abroad with which I am familiar do they use special mains. There are probably a quarter a million pressure wave lighters in use on the continent and in England. There is one company that I know of that has approximately ninety thousand street lamps and there are thirty or forty other companies in the field, so I presume probably a quarter of a million street lamps are lighted by this pressure wave system. For none of the street lamps do they have a special main for street lighting. I know of only two installations that exist in this country at the present time. In one of the largest cities in the country these pressure wave lighters are in use experimentally and perhaps a hundred of them are in use in one of the small districts of the city served from the regular distribution mains. In another city in this country, a city of about a hundred thousand people, there are two suburbs, one about twelve miles distant in one direction and another about eight miles distant in the opposite direction. The street lamps in these two suburbs are lighted by means of a pressure wave put on at the central manufacturing plant in the central city. In neither case is there a special distribution system.

I make these remarks because as the report reads there might be some misunderstanding and it might cause some to think that special systems are necessary for the high pressure lighting and for the pressure wave ignition.

Mr. S. L. E. Rose:—I notice on the second page of Dr. Bell's report three methods of increasing the life of flame arc lamps. But no mention is made of enclosing the arc as a method of increasing the life of the electrodes. In this way the life has been increased to over one hundred hours. In the report the life is set down as seventy-five hours. As regards the decrease in candle-power, due to the deposit on the globe, this has been kept down by condensing chambers which collect the fumes. The decrease is about twenty to twenty-five per cent. of the initial candle-power. On the 5-ampere intensified arc lamp the life is about seventy-five to eighty hours instead of forty to fifty hours.

Mr. E. L. Elliott:—Dr. Bell speaks of the petty economy of using the smaller sized luminous arc for street lighting. There is another much more serious case of misplaced economy in the use of the magnetite arc lamp. The magnetite arc is without question the most dazzling of all commercial lighting mediums at the present time. The use of the clear globe it seems to me is a very decided backward step in illuminating engineering. It is getting back to the old days of the carbon arc lamp without a globe which was about the worst illuminant ever placed in a street. I can see no other reason for the failure to diffuse the light of the magnetite arc than one of economy. The absorption by such globes reduces the efficiency. The arc, as you know, gives a considerable proportion of blue which would entail a special loss of light if globes of opalescent glass were used. Opalescent glass globes have a selective absorption for blue, a great deal of the glass being out of the question for outdoor use for reasons of heating; but even so it must be deducted from the efficiency of the magnetite lamp.

The tendency which Dr. Bell also mentions in public lighting of getting as much glare as possible is an unfortunate one. It is probably one that we will outgrow. I am sorry to see it coming in again at all. The illuminating engineers should certainly

be interested in combating this unfortunate use of a light source that is in other respects inherently good.

Mr. L. B. Marks:—It seems to me that Dr. Bell has not laid sufficient stress upon what appears to me to be one of the greatest advances which has been made in recent years and especially during the past year, in systems of lighting industrial establishments. I refer to the use of systems of general illumination supplemented where necessary by localized illumination. Up to a comparatively few years ago we simply copied the old method that was used abroad particularly in Germany and in France, or hanging a drop lamp over the work to localize the light on the space to be illuminated, and ignored the general physiological questions involved. Only a few years ago any one traveling through the factories of the United States would find most of them, I dare say off-hand ninety per cent. of them, illuminated by drop lamps housed in opaque reflectors immediately over the work, practically without any general illumination in the shop. Even to-day, unfortunately, some of the largest factories and industrial establishments in the United States are so illuminated. The general tendency during the past year, I think, has been to get away from the strictly localized system of illumination and, broadly speaking, this change marks an epoch in illuminating engineering.

The tendency of the layman is to think that if he has only localized light on the work, he can get the best results not only from the standpoint of illumination but from the standpoint of economy. He usually can't understand that there may be ultimate economy in spending three times as much for his illumination.

There is another point that has occurred to me: I see no mention in the report of daylight illumination or the progress that has been made in the daylight illumination of interiors.

Mr. J. G. Henninger:—On the eighth page of this report is the following statement: "Reflectors for industrial work have been undergoing steady improvement so that at the present time a much larger variety of thoroughly good metal reflectors is available than could possibly have been found a year ago." There are a large number of reflector companies who are pushing this industry to the limit, and I think the statement can readily be made that there are between four and five times as many good

metal reflectors on the market to-day as there were a year ago.

Another point that has been exceptionally interesting to me has been the excellent efficiency of these units. The average figures for glass reflectors will be somewhere near twenty per cent. of total flux emitted from the lamp in the upper hemisphere and about sixty-five per cent. in the lower and between forty and fifty in the sixty degree zone. In a good many of the metal reflectors it has been easily possible to get an average of sixty-five per cent. total flux from the lamps in the lower hemisphere I have several instances in mind where as high as 86 per cent. total flux in the lower hemisphere was obtained, the spherical efficiency being 91 per cent., and I think that is pretty good. There has been quite a number of reflectors that will average as high as 65 per cent. in the sixty degree zone. The excellent efficiency of this class of reflectors should be kept well in mind.

Mr. J. R. Cravath:—I want to second all Mr. Marks has said about importance of general lighting compared with localized lighting in factories, in fact, in nearly all classes of illumination work. Some tests that I have recently conducted have brought that out very strongly, but I will not dwell on it at any greater length here because I am to take it up in a paper of my own at a later session. We must consider not only quantity of light but quality of light that we get on the work. We must talk quality from now on more than we have in the past.

I would like to ask Mr. Henninger who gave those figures on the light flux of the lower hemisphere with different metal reflectors, whether or not those figures were on the total light flux of the lamp or the total light flux which is emitted from the reflector?

Mr. J. G. Henninger:—From the lamp.

Mr. J. R. Cravath:—Was I correct in understanding you to say some gave as high as ninety per cent?

Mr. J. G. Henninger:—In one or two isolated cases.

RECENT SMALL GAS LIGHTING UNITS.[1]

BY F. H. GILPIN.

In the general development of the present systems of interior lighting by gas, especially in residences, necessity has arisen for more variety in small sized units.

The electrical interests have for some time supplied units of almost any size and to suit every need. Formerly it was 8, 16 and 32 candle-power carbon units; later the same size in the metallized filament type and, lately, the 20 and 40 candle-power tantalum and 20, 32 and 48 candle-power tungsten units, which give an approximate mean spherical candle-power of about 7, 14 and 28 for the carbon and metallized filaments and 17.5 and 35, and 17.5, 28 and 42 for the new filament lamps.

In contrast with this the gas industry has long contented itself with single inverted units of 50 mean spherical candle-power and upright units of about 85 mean spherical candle-power, all the arcs and larger lamps being mere multiples of these units. It is seen that the smaller of these units is larger than the largest incandescent electric lamp commonly used in the interior field.

German and English manufacturers were the pioneers in the development of a smaller unit that should occupy a position so that its light flux would be one-half that of the former smallest gas unit. The first development was an upright burner, but later inverted burners of the "midget" type, so designed as to give about 25 mean spherical candle-power, were introduced.

The field that is opened by the use of a small unit of this type can be readily apprehended. The introduction of the so-called junior upright burner opened the way for the replacement of a large number of open flame burners without requiring any change in fixture or glassware. This, however, did not to any great extent improve the effective distribution, especially in a majority of cases where the old glassware was adhered to, which emphasized the poor distribution by brightening the upper hemi-

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

sphere and showing a greater contrast of light and shade than before. By slight changes it is possible in many cases to employ the new types of inverted "midget" lamps with their own glassware, which is usually designed to distribute the light flux to the best advantage.

Also, there arise situations where a 50 mean spherical candlepower unit would give such a great excess of light as to make its use uneconomical. For such occasions the small unit is especially advantageous, and for this purpose its development should be continued.

During the last year and a half, or two years, several small gas lighting units of this type have been examined and tested in various ways to determine their usefulness under varying conditions. Seven of these lamps, lettered respectively A, B. C. D, E, F and G, will be compared and their relative efficiencies tabulated and discussed.

Lamps A and F are of German, B, D and G of English and C and E of American design. They show in approximately the same order the care taken in, and extra workmanship given to, the minor details of manufacture.

TABLE I.

Lamp	Gas adjustment	Air adjustment	Bunsen tube	Injector or raceway	Enlarged mixing chamber	Gauze	Burner tip	Inner cylinder	Globe
A	Yes Down	Yes	Straight	Yes	Yes	No	Magnesia	Draft	Closed
B	Yes Down	Yes	Injector shape	No	No	No	Metal	No	Open
C	Yes Up	No	Semi-circular	No	No	No	Metal	No	Air-hole
D	Yes Down	Yes	Straight	No	No	No	Porcelain	No	Open
E	Yes Down	Yes	Straight	No Mesh	Yes	No. 18	Magnesia	No	Open
F	Yes Down	Yes	Straight	No	Yes	No	Magnesia	Draft	Closed
G	No Down	Yes	Straight	Yes	Yes	1 No. 28 1 No. 24	Metal	No	Closed

A—Bunsen protected from products by partitions in shell.

D—Lower half of bunsen of porcelain.

E—Very long burner tip. Bunsen protected as A.

F—Thermostatic primary air control. Bunsen protected as A.

G—Mixing chamber filled with baffles to act as regenerator.

Table I outlines the general points in which the construction of the lamps differ as to the methods of introducing and regulating the gas and air supply to obtain a satisfactory mixture.

In table II are given the results obtained with these lamps at various pressures between 2.0 and 4.5 inches of water. All the

TABLE II.

Lamp	Pressure	Consumption	Mean spherical candle-power	Mean spherical candle-power per cu. ft.	Lumens	Lumens per British thermal unit per hr.
A....	1.5	1.44	35.8	24.86	450	0.487
	2.0	1.62	41.0	25.31	515	0.496
	2.5	1.63	42.8	25.89	538	0.508
	3.0	1.63	43.4	26.64	545	0.522
	3.5	1.66	43.7	26.18	549	0.514
	4.0	1.77	45.1	25.50	567	0.500
	4.5	1.94	46.9	24.18	589	0.474
	5.0	2.01	47.8	23.78	601	0.466
B....	2.0	1.10	29.2	26.44	367	0.507
	2.5	1.31	35.9	27.40	451	0.524
	3.5	1.57	40.3	25.66	506	0.491
	4.5	1.85	42.3	22.89	532	0.438
C....	2.0	1.01	15.2	15.00	191	0.303
	2.5	1.16	17.4	15.03	219	0.304
	3.5	1.30	20.3	15.59	255	0.316
	4.5	1.39	23.0	16.55	289	0.335
D....	2.0	1.03	25.4	24.70	319	0.471
	2.5	1.15	27.7	24.10	348	0.461
	3.5	1.21	29.0	23.95	365	0.459
	4.5	1.35	31.7	23.47	399	0.449
E....	2.0	1.40	27.8	19.90	350	0.378
	2.5	1.73	35.0	20.20	440	0.384
	3.5	1.83	36.0	19.70	453	0.374
	4.5	2.06	40.0	19.40	503	0.369
F....	2.0	0.97	21.7	22.36	273	0.439
	2.5	1.21	22.5	18.58	283	0.364
	3.5	1.38	23.6	17.10	297	0.331
	4.5	1.47	22.8	15.46	287	0.300
G....	3.0	0.551	6.7	12.19	84	0.255
	4.0	0.62	11.7	18.87	147	0.391
	6.0	0.711	16.8	23.62	211	0.490
	8.0	0.882	21.0	23.86	264	0.495
	10.0	0.982	24.4	24.86	317	0.516
Average of 18 larger units				17.77		0.345

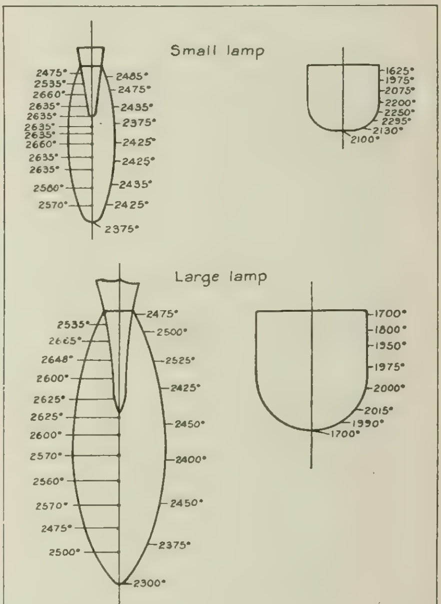
values given have been reduced to the common equivalent of a clear glass globe by determining the relative absorptions of the various globes with which the lamps were originally equipped. This was done to facilitate a more satisfactory comparison of the various candle-powers and efficiencies. All tests were made on an average mixed (coal and water) gas of specific gravity of about 0.66 and gross heating value of between 600 and 650 British thermal units per cubic foot. In the last column is given an efficiency factor of lumens per British thermal unit per hour. This forms a very good method of comparison with the electrical rating of lumens per watt and gives as a basis an actual measurable quantity of mechanical energy of input compared to a physiological measure of useful output.

It will be noted that with the exception of C and G all the lamps gave a uniformly high efficiency, showing a maximum at what is generally accepted as normal pressure, that is between 2.0 and 2.5 inches of water. This efficiency is higher by about 25 to 30 per cent. than that shown at the bottom of the table as the average efficiency obtained from eighteen units designated as "larger" and having an approximate mean spherical candle-power of 50. The exceptions in the cases of the lamps cited may be readily explained. In lamp C the curved bunsen tube and primary air ports are of such design that at normal pressure a supply of primary air sufficient for good combustion of the gas necessary to fill out the mantle cannot be entrained; consequently, as the pressure is raised, the jet velocity, due to the greater constriction of the orifice, is increased, a larger volume of air in proportion to the volume of gas is entrained and better combustion is obtained.

In lamp G the gas and air are previously mixed in the proportion of two volumes of gas to three volumes of air and by suitable mechanical apparatus the mixture is supplied to the lamp at a considerable increase above the normal operating pressure for low-pressure lamps.

As previously noted, the efficiency of the small units is from 25 to 30 per cent. above that generally obtained from similar units of larger size. This effect may be due to various causes, but one reason is the relative temperatures of the mantles.

In order to form some idea of the extent to which the mantle causes this difference of efficiency between the large and the small units, a short investigation was made of the relative flame and mantle temperatures of two lamps of the same make but of different sizes. The same procedure was followed in testing both lamps. A new lamp was erected and fitted with a new mantle that appeared to be of average size and shape upon inspection. No glassware was used. After burning off the



Flame and mantle temperatures

Fig 1.

mantle the lamp was adjusted at 2.5 inches pressure to a point of maximum brilliancy. After the lamp and mantle had become thoroughly heated temperature readings were obtained at uniform distances on the surface of the mantle by means of a platinum-rhodium thermo-couple having a bead of 0.028 in. (0.71 mm.) diameter and standardized in connection with a milli-voltmeter. The mantle was then removed and without readjustment temperature readings were taken in a similar manner on the surface and in the interior of the flame. The dimensions

of the free flames were also ascertained. The mantle was then replaced and check measurements made.

In fig. 1 are shown full size sketches of the flames and mantles, with the temperatures recorded. The averages show the remarkable difference in mantle temperatures obtained with practically the same unconfined flame temperatures:

TABLE III.

	25 c-p. unit	50 c-p. unit
Gas	Mixed	Mixed
Pressure	2.5 in.	2.5 in.
British thermal units of gas	675	675
Consumption (cu. ft.) per hour	1.67	3.50
Average flame temperature °F. (Abs.)	2,988	2,979
Average mantle temperature °F. (Abs.)	2,542	2,352
Projected luminous area	0.75 sq. in.	1.97 sq. in.
Surface area	2.53 sq. in.	6.66 sq. in.
Volume mantle	.491 cu. in.	1.935 cu. in.
Volume free flame	.353 cu. in.	2.128 cu. in.
Weight (sq. in.) mantle ash	.06392 grams	.0688 grams
Total weight luminous mantle	.16172 grams	.45821 grams
British thermal units per hour per 0.1 gram ash	697	515

In the ratio of "British thermal unit per hour per 0.1 gram ash" may be found the solution of the higher temperature and efficiency. The increase of heat added per unit weight of ash is $\frac{182}{492} \times 100 = 37.0$ per cent.; the increase of temperature is $\frac{190}{2,352} \times 100 = 8.1$ per cent. and the approximate ratio of energy emitted $\frac{(2,552)^4}{(2,352)^4} = 1.365$, or an excess of 36.5 per cent. As the lamps cited, with the exceptions of C and G, show a relative efficiency of $\frac{0.468}{0.345} = 1.355$, the analogy between the heat supplied, radiation theoretically expended and the luminous efficiency is very close. Again, the ratio of the free flame volume to the enclosed mantle volume may have some relation to the temperature to which the mantle may be raised. In case of restricted outflow between the mantle ring and burner nozzle, combustion may be incomplete, while with too large an opening an excess of air may be entrained and the temperature of the mantle may

not reach the possible maximum. In any case the temperatures of the flames obtained by properly burning a uniform sample of gas should be the same, independent of the sizes of the flames, provided that the air supply can be regulated with sufficient accuracy. It has been found from several tests that a lamp equipped with a mantle having a low weight of ash per unit area gives a considerably higher efficiency than one equipped with a heavier mantle. The limited range of this short experiment does not warrant the forming of a definite theory, but the comparison is of interest, inasmuch as it apparently corroborates the actual photometric efficiencies obtained.

The extent of one's knowledge of any type of lamp should not end here. It should not be restricted to the determination of the initial efficiency and the character of the distribution curve. The characteristic that is of greatest value in determining the utility and advantage of one type over another is its ability to endure continuous use, maintaining a high percentage of its original efficiency and preserving its mechanical properties over a considerable period of time.

At least three elements determine the success of a gas unit. First, the point having possibly the greatest importance is the mantle. On its mechanical structure and chemical saturation depends its ability to withstand shocks and hard use. Here is where the installation not under maintenance shows most conspicuously its deterioration. Secondly should be considered the structure of the burner itself. On the smoothness of the interior finish depends the amount of trouble caused by stoppage due to the accumulation of dirt and dust, fouling of orifices and gauzes and the corrosion of important parts. These troubles may at times be beyond immediate remedy and result in the condemning and discarding of the lamp. Third, while less trouble is incident to the breakage and soiling of glassware, yet care should be taken in the design, so as to permit of easy removal for replacement by cleaning. The first two points mentioned are of great importance, inasmuch as they are beyond the control of the average user of gas and directly affect the performance of the lamp.

As a criterion of the possibilities of these lamps, when operated under actual service conditions, each lamp was subjected to what might be termed a maintenance period test of ten days. The lamps were burned for five hours each day, using a uniform gas at a constant pressure, making a total burning time of fifty hours. No change of adjustment was made during this period, unless absolutely necessary, and each lamp was operated with the equipment supplied. Upon removing the lamps from the test a first candle-power measurement and efficiency determination was made with the lamp in the condition as found and a second reading obtained after all the glassware had been thoroughly cleaned.

Whenever a lamp showed unusual promise a further "life test" of 1,000 hours continuous burning was resorted to, slight changes in adjustment being made from time to time when necessary.

A summary of the short tests is given in table IV and the special 1,000 hour tests in table V.

The common electrical practise is to consider a lamp as having outlived its usefulness when the candle-power has fallen below 80 per cent. of the initial value. There is no reason why this should not be considered good practise in the gas lighting industry. This suggestion is not made with the idea that a new lamp should be supplied, but that when the value of a lamp falls below the 80 per cent. limit it should be thoroughly cleaned internally as well as externally and put back into service. The loss in candle-power due to the collection of dust and dirt on the glassware and the protecting shades should not be charged against the lamp, as the depreciation resulting from this source will be on an average, under reasonably clean conditions of use, between 8 and 10 per cent. during one thousand hours. As shown in table IV the loss due to other causes than accumulation of dust on the glassware during a maintenance period depends to a great extent on the condition of the mantle. One lamp actually showed a gain in candle-power, while all the others, with the exception of lamp C, showed a net candle-power loss of between 3 and 5 per cent. The mantle in lamp C was considerably carbonized at the end of the run, a condition accounted for by reasons stated under the discussion of the lamp construction. The losses due

TABLE IV.

	Before test						After test of 50 hours						
Lamp	Con-sump-tion	Mean spherical candle-power	Mean spherical candle-power per cubic foot	Lumens	Lumens per British thermal unit		Con-sump-tion	Mean spherical candle-power	Mean spherical candle-power per cubic foot	Lumens	Lumens per British thermal unit	Loss in candle-power per cent.	Loss in efficiency per cent.
A	1.61	42.4	26.35	532	0.515	*c*	1.68	39.1	23.25	491	0.455	8.0	11.5
						d	1.42	28.6	20.15	359	0.395	32.5	23.2
B	1.10	29.2	26.44	367	0.507	*a*	1.18	31.5	26.71	396	0.552	+1.0	+8.1
						b	1.18	33.0	27.95	415	0.578	+5.3	+12.2
C	1.01	15.2	15.00	191	0.303	*a*	1.03	8.0	7.74	101	0.157	47.4	47.7
						b	1.03	11.7	11.39	147	0.232	22.5	23.2
D	1.03	25.4	24.70	319	0.471	*a*	1.01	22.2	22.75	279	0.459	12.3	3.0
						b	1.01	24.3	22.15	306	0.500	4.5	+5.5
E	1.72	35.6	20.70	447	0.400	*a*	1.72	33.5	19.50	421	0.378	5.9	5.5
						b	1.74	34.5	19.80	434	0.384	3.1	4.0
F	1.21	22.5	18.58	283	0.364	*a*	1.11	19.2	17.18	241	0.347	13.6	4.6
						b	1.11	21.7	19.53	273	0.397	3.7	+9.2
G		No test.											

a = Readings taken with dirty glassware.
b = Readings taken with glassware clean.
c = After 50 hours, d = After 250 hours } glassware not cleaned.
+ = Gain.

TABLE V.

(Values not corrected for opacity of glassware).

	Initial						After 1,000 hours						
Lamp	Con-sumption	Mean spherical candle-power	Mean spherical candle-power per cubic foot	Lumens	Lumens per British thermal unit		Con-sumption	Mean spherical candle-power	Mean spherical candle-power per cubic foot	Lumens	Lumens per British thermal unit	Loss in candle-power per cent.	Loss in efficiency per cent.
A	1.89	38.0	20.10	477	0.383	*a*	1.80	23.2	12.89	291	0.254	38.9	33.6
						b	1.80	26.2	14.55	329	0.287	31.0	25.0
B	1.02	15.6	15.29	196	0.292	*a*	1.05	12.0	11.43	151	0.226	23.0	22.6
						b	1.06	13.5	12.73	169	0.251	13.4	21.4
D	1.36	22.4	16.48	281	0.314	*a*	1.23	17.5	14.22	220	0.281	21.8	10.5
						b	1.25	19.5	15.60	245	0.308	12.9	2.0
E	1.50	32.6	21.71	409	0.414	*a*	1.69	25.5	15.09	320	0.298	21.8	28.0
						b	1.69	28.0	16.56	351	0.327	14.0	21.0

a = Before cleaning glassware.
b After cleaning glassware.

AVERAGE PERFORMANCE.

	Lamp A		Lamp B		Lamp D		Lamp E	
	Candle-power	Efficiency	Candle-power	Efficiency	Candle-power	Efficiency	Candle-power	Efficiency
First hour	38.0	0.383	15.6	0.292	22.4	0.314	32.6	0.414
1,000th hour. (Dirty) ..	23.2	0.254	12.0	0.226	17.5	0.281	25.5	0.298
Average	30.6	0.319	13.8	0.259	20.0	0.298	29.1	0.356
First hour	38.0	0.383	15.6	0.292	22.4	0.314	32.6	0.414
1,000th hour. (Clean) ..	26.2	0.287	13.5	0.251	19.5	0.308	28.0	0.327
Average	32.1	0.335	14.6	0.272	21.0	0.311	30.3	0.370
Unit value......	30		15		20		30	
Absorption of globes				27.1%		30.0%		

to soiled glassware were variable on account of greatly different atmospheric and interior conditions at the times of the tests. In the 1,000 hour test the net loss was considerably less than 20 per cent., though the actual loss was greater.

Some effort was made in connection with the 1,000 hour service test to find a relation between the loss in candle-power and the weight of the mantle per square inch. As numerous mantles having a unit weight of about 0.069 grams per square inch had shown exceptionally good results in life and candle-power, this weight was adopted as a temporary mantle standard. Other mantles were examined that showed a very high initial candle-power and efficiency, but a very short life. These were found to have a low weight per unit area and were designated as "flash." In the 1,000 hour test the weights of the mantles as found were:

Lamp	Weight of mantle per square inch
A	0.05000 grams
B	0.04004 "
D	0.05624 "
E	0.06392 "

The life-test results obtained are not in strict accordance with the "flash" mantle theory, inasmuch as the lightest mantle gave as satisfactory results as the heavier ones.

There may be a lower unit weight that would be satisfactory for use with the smaller mantle, owing to the mantle's greater structural strength, due to its smaller size and consequently less strain on the fibers near the ring. This, however, is a point as yet undetermined, though the results recorded above, which are strangely at variance with the larger units under the same conditions, show a marked tendency toward such a theory. However, further experience in this direction would be necessary to prove the point one way or the other.

In addition to the small inverted burners, several of the upright type have been used for comparison. These should also be considered in the general selection of small gas units. Four burners are listed below and described.

Lamp H is an American type, previously described before this society by Mr. Macbeth, with an extra section added to the mica chimney.

Lamp I is a medium sized unit of German manufacture.

Lamps J and K are of English origin. Both lamps are of the same design, but one has about twice the lighting value of the other, though their actual size is very nearly the same. Lamp J may be considered a 25- and lamp K a 50-candle-power unit.

In table VI is given a summary of the efficiencies of these lamps obtained under similar conditions to those given for the inverted types, and in table VII are shown the results of the 50 hours maintenance period tests similar to the ones cited for the inverted lamps.

TABLE VI.

Lamp	Pressure	Consumption	Mean spherical candle-power	Mean spherical candle-power per cu. ft.	Lumens	Lumens per British thermal unit
H	2.0	2.28	36.9	16.18	464	0.320
	2.5	2.39	39.2	16.40	491	0.324
	3.5	2.60	42.8	16.46	537	0.325
	4.5	3.15	44.7	14.19	561	0.281
I	1.5	2.15	40.8	18.98	502	0.385
	2.0	2.31	51.3	20.40	644	0.414
	2.5	2.89	55.2	19.10	693	0.388
	3.5	3.53	59.5	16.85	746	0.342
	4.5	3.97	64.0	16.12	803	0.328
J	1.5	0.94	17.6	18.70	221	0.366
	2.0	1.12	23.0	20.50	289	0.402
	2.5	1.26	28.4	22.50	356	0.440
	3.5	1.52	33.5	22.00	420	0.430
	4.5	1.70	37.2	21.90	467	0.428
K	1.5	2.08	28.5	13 70	357	0.268
	2.0	2.45	45.0	18.36	565	0.360
	2.5	2.86	54.0	18.87	678	0.370
	3.5	3.38	62.5	18.48	784	0.362
	4.5	3.78	69.3	18.33	870	0.359

Here again is encountered the same tendency of the smaller units to give a considerably higher efficiency than the larger ones. A striking comparison is shown in the results from Lamps J and K. These two lamps are identical in every particular of design, but the small unit gives a 20 per cent. higher efficiency than the larger one. The low efficiency of lamp H is due in a great part to the higher absorption by the mica chimney.

In the "maintenance" period test some remarkable results were obtained, especially with lamps J and K. These lamps show a positive increase in both candle-power and efficiency.

TABLE VII.

Before test

Lamp	Consumption	Mean spherical candle-power	Mean spherical candle-power per cu. ft.	Lumens	Lumens per British thermal unit
H	2.28	36.9	16.18	464	0.320
I	2.89	55.2	19.10	693	0.388
J	1.26	28.4	22.50	356	0.440
K	2.86	54.0	18.87	678	0.370

After test of 50 hours

Lamp		Consumption	Mean spherical candle-power	Mean spherical candle-power per cu. ft.	Lumens	Lumens per British thermal unit	Loss in candle-power per cent.	Loss in efficiency per cent.
H	a	2.42	33.8	13.92	424	0.287	8.4	11.5
	b	2.39	35.7	14.93	448	0.308	3.2	3.8
I	a	2.98	54.9	18.43	689	0.361	0.6	7.0
	b	2.98	55.1	18.48	691	0.362	0.2	6.7
J	a	1.31	29.3	22.40	368	0.454	+3.2	+3.2
	b	1.31	30.2	23.10	379	0.469	+6.3	+6.6
K	a	2.92	55.2	18.90	693	0.370	+2.2	+3.8
	b	2.92	57.2	19.57	718	0.397	+5.9	+7.3

a before cleaning. b after cleaning. + gain.

The question of mantles again enters into the results. The weights of the mantles with which these upright lamps were equipped are given below:

Lamp H = 0.05500 grams per square inch.
Lamp I = 0.03624 " " " "
Lamp J = 0.06528 " " " "
Lamp K 0.06380 " " " "

In addition, the mantles of lamps J and K were hardened before being collodionized. This will account partly for the increase in candle-power and efficiency during the first fifty hours.

The loss due to dirty glassware is only about 60 per cent. of that incurred with the inverted types.

In all types of the small units danger due to the breakage of glassware is greatly diminished and the possibly resultant damage reduced. The increase in efficiency means a decrease in consumption and results in what might be considered a cooler installation.

Finally, further attention should be paid to increasing the number of sizes of lamps available, the investigations being so directed as to produce higher efficiencies at usual gas pressures.

DISCUSSION.

Mr. T. J. Litle:—Mr. Gilpin's paper is the most complete paper of its kind I have ever read. But in comparing the particular small units with the large ones I hardly think he has definitely proven the fact that the small units will necessarily be higher in efficiency than the large. He has, however, undoubtedly proven that the small units he selected for his tests were very much more efficient than the large burners which he selected. In making that statement I refer to the test of small sized inverted lamps as compared with the larger size of lamps with ratings of 25 and 50 mean spherical candles reflected.

It will be noted too in this paper that, apparently, the small units, inverted units, were mostly of the stack type. It is conceded of course that the stack type of burner, as applied to inverted burners particularly is more efficient than the non-stack type. Recent tests of the stack type of large sized units show a higher efficiency than that obtained in former tests.

The statement that the large gas units can be rated at 50 mean spherical candle-power can probably be modified to read from 60 to 70 mean spherical candle-power. Recent tests that I have observed have indicated as high as 71 mean spherical candles on the larger types of burners.

The mesh of the mantles under consideration of course is a very important factor. Mantles in some cases are particularly high in hydrogen and with coal gases one finds that a great deal larger air supply is necessary than in the combustion of other gases. If one places a very close mesh mantle on coal gas, the combustion will not be perfect. In other words, the combustion will be impeded and the character of the naked flame will be changed. In the case of water gas being used on the same mantle, the efficiency will very often be reversed, the only mechanical difference being in the mesh of the mantle. In these particular tests I think most of the lamps were made for coal gas, and the gas used on the test was a mixture of coal and water gas, so that an exact comparison could hardly be obtained in that way.

The mean spherical candle-power of lamp B is recorded as 15; while the mean spherical candle-power of lamp E is down

as 32.6. The gas consumption of lamp B was very low, and the gas consumption lamp B was greater. It may have happened that the gas orifice on burner B was considerably smaller than it should have been for the kind of gas used. In other words, I suspect that the orifice was designed for the use of coal gas and the mixture of coal and water gas, having greater gravity, the orifice was not sufficiently large to make it burn to its full incandescence. The size of the mantle on burner B I don't think is stated, while the efficiency is very high.

The conclusions that are deduced in the paper would lead one to believe that the small mantle was necessarily more efficient than the large one. I hardly think that is so. However, if exactly the same mantle in each case is used, that is the same mantle structure, the mantle designated as flash mantle when made in a certain way can be expected to give a very much higher efficiency than the stable mantle which is supplied on the American market.

I would like to ask the author whether in determining the performance of the 18 burners of a large size the heavy mantles as shown were used; I suppose they were; and whether any of the lighter mantles, or flash type mantles, were used in the same test to determine the difference between the flash mantle and the heavy mantle shown.

One other feature of mantles has not been mentioned; that is the value of the light emitted from the interior of the mantle. I have never heard that point discussed; but undoubtedly there is some light emitted from the interior surface of the mantle which should be taken into consideration; and the more open the mantle is left the more of that light it seems to me is available. I frequently notice very open mesh mantles perform very much better and give a higher efficiency on a given flame than a closer mesh. The total weight of ash in the mantle does not necessarily signify its performance as compared with lighter ash mantles unless the mesh is changed. The changing of both the mesh and the weight of ash has a very peculiar effect upon the efficiency of the mantle.

I would like to mention that the possibility of increasing the efficiency of the larger burners is very great, and that at the

present time the value of 50 mean spherical candle-power for the large or standard size burner, I think, is a little low. I can state that the stack burner, which is coming, is considerably higher.

Mr. F. H. Gilpin:—In reply to Mr. Litle I can not say whether all these burners were designed for coal or water or mixed gas, but the majority of them gave higher efficiencies on mixed gas than on coal gas. I have not the figures with me for it, but if I remember rightly, there was only one of the whole set that gave better results on coal gas than on mixed gas.

In regard to the question of the relative size of lamps B and E: lamp B has a considerably smaller mantle than lamp E and naturally would burn much less gas, though it gives a higher efficiency. Neither lamps B or C are stack lamps. One of them gives very good efficiency and one very poor: whereas A, E and F are stack lamps and are not particularly higher in value than B and D. Tests have been made using a flash mantle and what might be called a standard mantle. In some cases the mantles were not the same shape and did not give very good comparative results, but such tests have been made and as a usual rule the lighter mantle gives the higher efficiency, though sometimes better efficiencies have been obtained with the heavier mantles than with the lighter mantles.

In this comparison of the flame temperatures of the two lamps the mantles used were very nearly of the same structure.

RECENT DEVELOPMENTS IN THE MANUFACTURE OF INCANDESCENT ELECTRIC LAMPS.[1]

BY J. E. RANDALL.

By common usage, the name incandescent electric lamp has been limited to a lamp whose light source is the glow of a wire heated in vacuo by electric current. This paper will not use the name in any broader sense.

Incandescent electric lamps may be divided into two classes, depending upon whether their light-giving elements, that is their filaments, are made of carbon or of metal. At present the best examples of each class stand rather far apart both in appearance and in other features, although both are designed for the same service. One may be replaced by the other for nearly every use.

Lamps with carbon filaments have been supplied without any change in appearance for over eleven years. Within that period one notable improvement was introduced, namely, the metallized filament. Among the lamps with metal filaments, there has been, within the last five years, a procession of developments beginning with the osmium filament, the tantalum wire filament, the pressed tungsten filament, and ending with the drawn wire tungsten filament. The author shall attempt to briefly review the advances that have been made in the quality of the most prominent members of the two classes.

CARBON FILAMENT LAMPS.

The changes in quality of the regular carbon filament lamps of all standard wattages are shown in the subjoined table. Each year's quality is shown in comparison with the average of 1902.

Year	1902	1904	1906	1907	1908	1909	1910
Per cent. of 1902	100	98.4	96.9	96.9	100	103.1	107.8

A sag in quality is indicated from 1904 to 1907. This is accounted for by the larger proportion of wattages below 50 and

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 29 and 28, 1911.

above 100 that were produced during those years. The large and small wattage lamps are known to be inferior to those between 50 and 100 watts. Within recent years the production of high wattage lamps has diminished and doubtless will decrease still further. The proportion of low wattage lamps has been maintained and has held back the progress of average quality during the last three years. As a matter of fact, nearly every wattage shows a substantial improvement within the eight year period.

No changes have been made in the processes of manufacture. The record exhibits the results of systematically following each detail, of rigid inspection, of thorough, exact and extensive tests, of the immediate use of the latest developments in equipment and the unhesitating discard of unsuitable equipment, and of the services of trained operatives. The best lamps of ten years ago were as good as the best of the present year. The average has arisen due to the elimination of defectives.

The metallized carbon filament lamps, which are known as Gems, have made the advances shown by the following record—Calling the product of 1907 equal to 100; that of 1908 is 121; that of 1909 is 130; that of the past year is 133.

All conditions favorable to advancement of the regular carbon filament lamps were of similar assistance to the Gems. A discovery in connection with the preparation of the carbons for these lamps resulted in a decided improvement in 1909. Heretofore, wattages lower than 50 have not been made successfully. Recent experiments show that wattages as low as 30 can be made.

The Gem lamp shows a sufficient superiority in quality over the regular carbon filament lamp to justify its more extensive use.

METAL FILAMENT LAMPS.

As the developments in three metal filament lamps have been rapid, recent and thoroughly published, no extended description will be given in this paper.

The osmium lamp marks the beginning of development of metal filament lamps. It reached a successful commercial stage in Europe. Its great fragility and the difficulties met in fashioning the filament would, no doubt, have been eliminated had its devel-

opment not been arrested by the limited supply of osmium and by the advent of the tungsten filament.

The tantalum, nearly coeval with the osmium, was handicapped neither by fragility nor meager supply of metal. It is worthy of mention as an example of an article upon whose production years of research had been spent, upon whose design lavish experiments had been made. When first offered to the public, its design was finished and its qualities were thoroughly known. The inferior performance, due to offsetting, on alternating current was announced at the time the lamp was announced. The mechanical weakening of the tantalum wire, due to offsetting when kept on alternating current, has prevented the general introduction of the tantalum lamp in this country.

This lamp, however, was the first production of a real drawn wire lamp and its development required a construction of the filament supporting element different from any that had been used heretofore. The design of support employed in the tantalum lamp has been followed, with slight modifications, in the drawn wire tungsten filament lamp. The tantalum lamp cannot continue to compete with the drawn wire tungsten filament lamp in its present form.

The tungsten filament lamp was the immediate successor of the osmium lamp. The superiority of tungsten for a lamp filament was immediately recognized because of its extremely high melting point and because its boiling point is not greatly below its melting point. The brittleness of the pressed filament, especially when it is cool, has been a serious drawback to the general use of the lamp. The attachment of the filament rigidly to the circuit connections and to the intermediate connections between the filaments has probably been the chief cause for filament breakage in these lamps. The arced joint, while it was perfect electrically and mechanically, held the filament ends rigidly. Any jar to the lamp tended to make the filament vibrate and usually to break close to the joint. The schemes that were devised for avoiding this filament breakage were legion, but the author believes he is safe in saying that the loose contact at the bend of the filament with a support that was rigid made the hardiest lamp of the pressed filament type.

One of the most successful devices for preventing the breakage of filaments was that of introducing a short piece of piano wire between the center rod and the stem seal. This supported the filament structure with remarkable flexibility and prevented breakage from blows on the lamp in almost any direction. A slight blow upon the base of the lamp was invariably fatal and this one weak feature served to prevent the general introduction of this method of support.

The pressed tungsten filament is not ductile when cold, no matter by what process it may have been produced. Although pressed filaments have been made that could be bent and that would take a permanent set if bent, these filaments were not truly ductile. It was natural, therefore, that immediate effort should be made to develop a quality of tungsten sufficiently ductile to be wrought into the form of wire. There was nothing to prevent success in this endeavor except lack of knowledge. It had been demonstrated that tantalum, which had been known as an extremely brittle metal, could be so improved in purity that it would be ductile. This knowledge would naturally lead to the belief that many of the metals which had been considered as non-ductile could, if properly prepared, be made into ductile form. An epitome of the progress in developing ductile tungsten will read something like this:

In 1907 it was hoped that it would be possible to produce ductile tungsten; in 1908 it was believed that it would be possible to produce ductile tungsten; in 1909 experimenters were sure that ductile tungsten could be produced; in 1910 it had been proven beyond doubt that ductile tungsten could be produced; in 1911 ductile tungsten was produced on an extensive commercial scale.

It is generally believed that the presence of carbon in tungsten is the cause of its brittleness. One well known process for making pressed tungsten filaments does not involve the use of carbon, yet filaments produced by this process are as brittle as are filaments made by the use of carbon. As a matter of fact, the best pressed tungsten filaments have been those made by processes involving the use of carbon, yet they contain an amount of carbon so small that it can only be detected by the most delicate tests. For instance, filaments which are known to contain less than 0.005 per cent. carbon are no more ductile than those which

are found to contain 0.1 per cent. The elimination of carbon tended to reduce the length shrinkage of filaments when lamps were burned. It will be recalled that filaments produced in 1908 and 1909 sagged excessively and that the filaments often short-circuited due to this sag. The slack producing this sag was necessary because of the filament shrinkage. During the year 1909 decided improvements were made in this respect, and the basis of these improvements was the more complete elemination of carbon from the tungsten filament.

The progress during 1909 and 1910 did not indicate a material decrease in the fragility of the pressed filament.

It was evident, therefore, that to make the tungsten filament lamp a universal lamp, it would be necessary to have the filament in the form of wire which was sufficiently ductile to be wound, when cold, upon a spider structure. The drawn tungsten wire has met this need. While the wire before being placed in the lamp is amply ductile for the purpose of winding upon the spider and for all other manipulations needed in making the lamp, it loses much of this ductility when current is passed through it in a vacuum. The method of supporting the wire on the spider and of attaching it to the circuit terminals are, therefore, important factors in the hardiness of the lamp.

The wire may be considered to consist of pure tungsten. Chemical analysis does not find other elements. The ratio of resistance hot to resistance cold is as high as can be found in any other form of the metal. The specific gravity is higher than that found for the pressed filament. The current and the candle-power peaks are low.

The structure of the metal appears to be fibrous. It changes to the crystalline form during the burning life of the lamp. This change may occur in some portions of a filament and not in others. Frequently, after the full burning life, small sections of filaments will be found that show ductility.

Tests indicate that the wire is less brittle at every stage in the life of a lamp than are pressed filaments. There is no offsetting, either on direct or alternating current. The surface is the same in appearance, after the lamp has been burned, as that of a pressed filament. It looks as if the wire had been cracked into irregular pieces and as if a cement of the same material had filled up the

cracks. No fissures at the surface and no cavities in the body have been found.

While the wire, before being placed into the lamp, may be ranked with the toughest steel in tensile strength, ductility and elasticity, the decay of these properties after it is in the lamp makes it necessary to handle these lamps with reasonable care in order to prevent breakage. Breakage in transportation and handling compares with that for carbon filament lamps. Operatives in the lamp factories transfer lamps having wire filaments from operation to operation the same as if they had carbon filaments.

Another feature in which the drawn wire is superior is the wide range of sizes suitable for use. A piece of wire may be drawn to a size suitable for a 6.6 amperes series burning lamp or it may be drawn to a size suitable for a 20-watt, 110-volt multiple lamp. It will, when drawn to the proper diameter, be equally satisfactory for the largest or the smallest lamp. In addition, the wire may be shaped into helices, spirals or zig-zags; thereby concentrating the light-giving element into a small volume. The latest automobile lamp is an example.

The number of contacts between the filament and supports, including terminals, as well as the size and material of these supports, will affect the performance and physical hardiness of a lamp.

The following results were secured from three series of tests in each of which more than 300 drawn wire tungsten filament lamps were used:

No. of contacts	11	13	15
Comparative strength, by pendulum test—			
Copper	91.5	100	96.5
Molybdenum	..	..	93.0
Comparative performance at normal efficiency—			
Copper	99.4	100	96.1
Comparative life at extreme temperature			
Copper	107.0	100	87
Molybdenum	..	..	103

The lamps were standard in voltage and all were 40 watts. They were identical except in the number of filament contacts. The results of the first and second tests confirm one another in indicating that 13 contacts are most satisfactory.

While no record is shown for molybdenum support lamps at normal efficiency, such lamps were tested, but their performance was much more poorer than the corresponding copper support lamps.

The comparative lives at extreme temperature show that 11 contacts are better than 13 and that 13 are better than 15. Also that 15 molybdenum contacts are better than 13 copper, but inferior to 11 copper. These results are not in consonance with the results at normal efficiency. It is reasonable to believe that tests at, or near, normal efficiency indicate more accurately the behavior of lamps in service than do those at high temperatures. It has been observed that the wire in lamps burned out when at high temperature remains more ductile than the wire in lamps burned out at normal temperatures. The early failure of 15 contact lamps would not be explained by mechanical weakness. The wires usually "burned out," or melted, between the supports. The melting of the wire at the point of highest temperature has really controlled the life record of this test. The diameter of all copper supports was the same. The diameter of the molybdenum was 40 per cent. of that of the copper. Supports of copper having diameters 30 per cent. smaller and 30 per cent. larger than the size used in the above tests both showed a lower strength by pendulum test. The author cannot explain why this should be so, but the tests were convincing.

Having traced recent developments up to the latest, it may not be amiss to consider the future. If the progress in lamp development may be gaged by the highest filament temperature at which each new lamp will show a given performance, one has a rational measure. For example, if 90 per cent. of the theoretical candle-power hours are developed in 1,000 hours burning, candle maintenance and mortality both considered, the advance from the raw carbon filament lamp to the tungsten filament lamp will show something as follows:

Raw carbon filament lamp (cellulose carbon)	100
Treated carbon filament lamp	119
Metallized carbon filament lamp	149
Tantalum filament lamp	206
Osmium filament lamp	270
Tungsten filament lamp	359

This comparison excludes many items, such as process diffi-

culties, lack of wattage range, lack of voltage range, lack of suitability for both alternating and direct current, cost, etc., which affect commercial values. It is not a comparison of commercial values, although it is a comparison of the most important element in commercial values, namely, the energy wasted in doing equal work.

The change introduced by the metal filament lamp is noteworthy. Can carbon, with its many good qualities, reach or pass the record set by metals? The carbon deposited upon the treated carbon filament, when metallized, is dense, somewhat flexible, has a low vapor tension, has a fine quality of surface and has a cold specific resistance that is about 4 per cent. of carbon made from cellulose. All these qualities are favorable. Their further development may again place carbon in the race

DISCUSSION.

Mr. J. W. Howell:—I am sorry Mr. Randall gave the figures at the bottom of the first page of his paper just as he did, because those figures represent a combination of quality with quantity which I think is not a proper way to consider lamps; and when we remember that such tables and figures are very apt to be copied by the technical press, or other papers, without the full explanation which follows in this case, we ought to be careful not to present them in a way that they may be copied disadvantageously.

The figures on the last page of Mr. Randall's paper also, I think, are misleading. Those figures represent, as Mr. Randall very properly states, the energy wasted or the energy used by the different lamps in doing the same amount of work. Now, the energy which is used or wasted by any lamp depends upon its efficiency and, therefore, a comparison between lamps in which one wishes to show the energy used in doing a given amount of work should be made at the proper efficiency for each lamp. That has not been done in this case. The lamps in this case are operated so as to last a thousand hours. While that is probably the proper life for the tungsten lamp, it is not the proper life for the carbon lamp. Therefore, for the carbon lamp it is poorer, while for the tungsten lamp it is the proper efficiency. The comparison, as Mr. Randall states, is a comparison which

does not include the cost of either the current or the lamps. A proper comparison of carbon and tungsten lamps, must include the cost of current as well as the cost of the lamps, because it depends absolutely on the cost. Of course, a tungsten lamp has a value due to its color, but the greatest advantage is its economy of operation and this depends on the cost of current, and also on the cost of the lamp. If the current cost nothing nobody would buy the tungsten lamp at the present price; if lamps cost nothing nobody would use carbon lamps. To properly compare lamps each lamp must first be placed under proper conditions. We must assume conditions of cost of current and of cost of lamps; and for each of these get the maximum economical operation of the two types of lamps. Then they may be compared.

Mr. Randall has told us about the advent of the drawn tungsten wire lamp. He has not told us, however, which is probably a fact, that all tungsten lamps to-day are made with the drawn wire filaments. The pressed tungsten filament has passed away. At the General Electric Company, with which I am associated, the pressed filament is no longer made.

Mr. Randall has cited some of the advantages of the drawn wire filament. But, I think, he has not said enough about it. He mentions its strongness and its ruggedness; but he has not said anything about some of the other qualities which it has which are very important. For instance, it is made in one piece; instead of being made of four or five pieces. Also, it is stiffer at a given efficiency than is the pressed tungsten filament. We don't know any reason why it should be so, but it is a fact that at the same efficiency the drawn wire tungsten filament is stiffer than the pressed filament. The effect of this is noticeable when lamps are burned with their points upward. A pressed filament will become soft and sag downward; the two sides will approach each other and very often a little jar will cause them to over lap. This is observed in the drawn wire filament very much less than in the other; in fact, practically not at all. Then, there is another advantage in the drawn wire filaments which Mr. Randall has not mentioned, and that is the fact that they have only two heat conducting contracts, as one might say. The two ends of the drawn wire filament are fastened securely to

leading-in wires; those joints conduct heat. The filament simply hangs loosely on the other supports, so the heat contact is very poor and comparatively little heat is conducted away from the filament and lost; whereas in the pressed filament each end of each loop, and there are usually four or five or six loops, is soldered rigidly, making it a conducting joint which carries away a great deal of heat. This heat conducted away from the filament by the supporting wires of the pressed metal filament has been the cause of a good deal of trouble in high candle-power lamps where the filament was of considerable diameter. The avoidance of this loss in the drawn wire lamp has caused very considerable improvements in the large lamps. The high candle-power lamps are made of drawn wire.

I wish to state here that these large sized tungsten filament drawn wire lamps are very much better in quality than were the old pressed filament lamps of the same size. Further than that they are being improved very rapidly at the present time, and I venture to state that within a few months from now they will be very much better than they are to-day. I see the greatest value to the art of lighting in these large sized tungsten drawn wire filament lamps, and I hope that the illuminating engineers here will keep themselves acquainted with the various changes being made in the art of making high candle-power lamps.

I think also that Mr. Randall dismissed the Gem or metallized filament lamp with rather too little notice. He says it deserves more general use. So it does, and very much more general use. There is very little difference in the price between carbon filament lamps and metallized filament lamps. I think the difference is not over ten per cent. The improvement in quality which Mr. Randall speaks of as having been made in 1909 and 1910 is caused not by the inherent quality of the lamp as a lamp but in the reduction of the number of lamps which break early in their lives. This was the serious trouble with Gem lamps in the early years of their use, and it was a very annoying trouble. Lamps which break early are appreciated by every user; they are noticed, and it is the elimination of those early breaking lamps which has caused the general quality or general usefulness of the Gem lamp to be considerably increased as Mr. Randall shows. When one considers that the Gem lamp is about three times as good intrinsi-

cally at any given efficiency, that is three times as long lived as the carbon lamp, why do people buy carbon lamps when they are only about ten per cent. cheaper than the Gem lamps?

In speaking to illuminating engineers I want to deplore one fact which exists to-day, and that is the continued manufacture and sale of large carbon and Gem lamps because they are ordered. These lamps as high as fifty candle-power are made to-day; but they should not be made and sold to-day; they are back-numbers. A tungsten lamp of the same candle-power is so very much better in every respect that it seems to me the wrong practise for anybody to use a large carbon lamp, and I hope that you illuminating engineers will discourage the use of these large current consumers as much as you can.

Mr. G. C. Webster:—By way of comment on Mr. Randall's paper, I would like to call attention to the pronounced slump in lamp quality during the years 1904 and 1905. This decline of quality, I am convinced, was largely due to ruinous price-cutting, the natural result of which was to cheapen the product. Those of us who have had the experience of facing a pay-roll with inadequate funds in the bank know only too well the effects upon quality of such enforced economy.

It should be indelibly impressed upon the minds of illuminating engineers that where quality and service are desired a fair profit must be allowed the manufacturer. The saving of a few cents on the initial cost of a lamp or a reflector seldom results economically in the long run.

While to many the figures given may have been cold and meaningless, fifteen years of experience have substantiated my conviction that destructive competition was largely responsible for the poor quality; on the other hand, I am equally positive that the high grade of lamps to-day is due to the fact that the manufacturer is allowing a small amount of the profit per lamp each year for lamp development. It is the assurance of a conservative but safe margin of profit that has brought about the perfection of the tungsten lamp and has made the high efficiency lamp a commercial possibility.

Mr. Geo. H. Jones:—The manufacture of incandescent lamps has always been very interesting to me, especially so in view of the fact that an article requiring such skill in its production

can be manufactured and sold at about the same price as that charged for an ordinary lamp chimney. The great improvements which have been made from time to time in the incandescent lamp have been of much importance to both consumers and central station companies. Three or four years ago there was considerable apprehension in some quarters as to the effect the introduction of the modern high efficiency lamp would have on the central station business. The central station people in Chicago have always adopted lamps of the highest efficiency obtainable and will gladly welcome any improvements which the future may bring forth. They have always maintained the position that changes from the use of low efficiency to high efficiency lamps would be made gradually, so that the situation would automatically adjust itself to the new conditions. Furthermore, we have felt that the use of high efficiency lamps in the long run would even increase the consumption due to the desire on the part of the public for more light. I have prepared a few figures along this line to show the actual results from experience. The data covers the month of October for the years 1908, 1909, and 1910, and is as follows:

OCTOBER DATA.

Kilowatt hours per customer.

	1908	1909	1910
Flats	16	17	18.5
Houses	30	32	33
Small stores	46	48	79

These figures show a steady increase in consumption per customer, in spite of the introduction of high efficiency lamps. This increase is undoubtedly in part accounted for by the increased use of appliances of various kinds, and is also accounted for by the more liberal use of light. The showing in the case of the small stores is truly remarkable, but it is correct, as other months of the years in question show the same increase. Part of this increase is probably due to the fact that formerly some of the smaller merchants used electricity for a part of their installation, such as in show-windows and offices, and other illuminants in other parts of the store. These merchants are now using electricity exclusively.

Mr. P. S. Millar:—On the bottom of the first page of the

paper appears a table showing fluctuations in the values of carbon lamps. It seems to me that Mr. Randall as a manufacturer's representative has been modest in putting things in that way. Some time ago I had occasion to arrive at a generalization of that kind and from a study of the records I concluded that the improvement in carbon filament lamps during the past ten years class for class, might well be stated as from fifteen to twenty per cent.

I have had occasion to study Gem lamps in the last four or five years very carefully in the interest of purchasers. The standard against which the Gem lamp must of necessity be compared is the older carbon filament which has rendered such satisfactory service in general lighting. During the past year for the first time large purchasers came to the conclusion that the Gem lamp maintained that standard and exceeded it. Prior to that time there was some difficulty with the Gem lamp chiefly in the nature of early burn-outs and the very low degree of uniformity.

In regard to the new drawn wire lamps, the change which has taken place in some sizes as to the location of the center light source, or the length of the filament's cylinder, or the diameter of that cylinder, has altered light distribution curves as has been pointed out in discussion. In tests of reflectors it has been very important, of course, to secure the standard lamp, and in all testing work at the Electrical Testing Laboratories effort has been made to keep in the very closest touch with the manufacturers and with their standardization committee, and to secure for test purposes lamps which conform substantially to the latest standardization.

Referring to Mr. Jones' statements, I think that we as a society ought to recognize the progressive attitude of central stations such as the Commonwealth Edison Company who have placed tungsten lamps in the hands of their customers under the most attractive terms, standing ready at all times to sell lamps to their customers at prices which are below even their own cost price, and not only that but urging the use of tungsten lamps on the part of their customers. It is that attitude of the central stations which in a very large part has introduced the tungsten lamp against some inertia and reluctance on the part of the consumers as a whole.

Mr. W. F. Little:—To indicate the ruggedness or filament strength of tungsten lamps, a device as shown in the accompanying illustration has been constructed by the Electrical Testing Laboratories. The arm upon which the lamp is mounted is brought to a constant position by each revolution of a small cam, and is allowed to drop freely from this position upon a second cam constructed according to the principle of the spiral. The drop increases from 1/100 of an inch at the start to four inches maximum, having a constant increment of 1/100 inch per revolution. The fall at which the filament breaks is indicated directly upon a dial in hundredths of an inch by a pointer attached to the large cam. A delicate relay in series with the lamp filament and three dry cells indicates the breakage of the filament and at the same time serves to stop the motor. The resistance

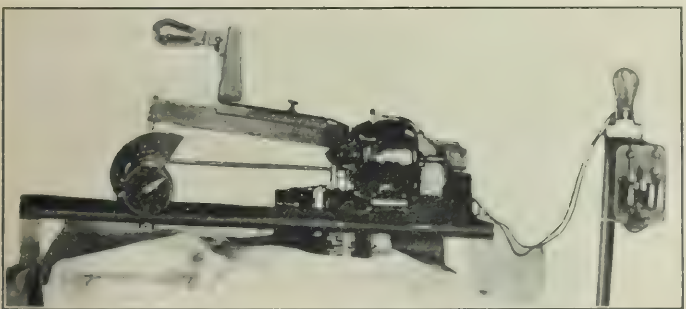


Fig. 1.—Apparatus for testing the ruggedness of tungsten lamp filaments.

of the relay and lamp combined is approximately 2,000 ohms, while the voltage applied is about 4 volts. Thus the current flowing through the filament is less than 0.002 of an ampere, or not sufficient to materially raise the filament's temperature.

A demonstration showing the superior ruggedness of the new type tungsten filament over the old was made with the following results:

	Old type tungsten filament	New type tungsten filament
25-watt lamp	0.06 in.	3.75 in.
60-watt lamp	1.15 in.	A fall of four inches failed to break the filament.

A carbon lamp remained intact throughout the maximum fall.

Mr. T. A. Aldrich:—I speak on this subject as a non-technical member, or one who has put into use the different makes of lamps as used to-day. I should like to say what the

tungsten lamp has done for the company I am with, the International Harvester Company. Two and one half years ago we started to find what was the best illuminant of the various types of lamps then in use for our different factories and offices. We made quite a complete test, including tungsten lamps. We put the tungsten lamps through some very severe tests throughout our works, and they turned out so satisfactorily that we decided to use them almost exclusively. At present we have between twelve and thirteen thousand tungsten lamps in use. The majority of them are installed in single units, and the balance of them are in clusters of four. Instead of getting a thousand hours, the guaranteed life, out of the 100 and 150-watt sizes, we are getting an average of from fifteen to eighteen hundred hours throughout our works and offices. We have trip hammers on some of the floors above these lamps in some of our works; but they still stand the racket. We have very nearly come to the conclusion that, neglecting the high ceilings in our steel mills and foundries, they are the most satisfactory illuminants we might install.

Mr. Norman Macbeth:—There is just one point I desire to cover in the discussion on this paper. On the fifth page of the paper is the statement "That to make the tungsten filament lamp the universal lamp, it would be necessary to have the filament of a wire which was sufficiently ductile to be wound when cold, upon a spider structure." This point of sufficient ductility to be wound when cold, is merely a manufacturing detail and is not the important point of advantage in the tungsten lamp having a filament in the form of a wire. The advantage, and I believe it will be generally admitted by those familiar with the development of these lamps, considered as a lamp from the standpoint of the consumer, is due more largely to the continuous filament construction now used by the manufacturers in the drawn wire lamp.

The fused type lamp had so many weak points inherent to that type of construction, that had any other lamp of equal efficiency of light production been available in sufficient quantities commercially, the manufacturers of the fused type lamp would have been driven earlier to the later improvements now available through the tungsten drawn wire.

The pressed filament in short lengths, formed like hair pins with four or more separate pieces of filament in each lamp, pieces which frequently varied in diameter and resistance, resulted in a construction far from satisfactory. The ultimate value of the lamp depended upon the weakest link, and a difference in filament diameter of 0.00001 of an inch with a corresponding difference in resistance, would be sufficient to shorten the life of a lamp one third. This difference is susceptible to very exact electrical measurement, and as a laboratory proposition would not be serious; but when applied to factory production mistakes were not unusual with the result with which we are all familiar.

My personal observations of the 25-watt fused type lamps of but a couple of years ago showed such unsatisfactory performance that dealers were forced to discontinue their use and return them in quantities to the manufacturers for credit. The continuous filament construction has resulted in such a considerable improvement in tungsten lamps that the 25-watt sizes are being used to-day in some localities in street car work, and I also understand that they are satisfactorily meeting the service conditions in some of the New York subway cars. Of course, the latter conditions may not be so severe as on the surface road, inasmuch as the lamps are on during practically all of the running time. The lamps of the continuous filament construction, to which I refer, were tungsten but were not of drawn wire.

A filament of drawn wire did not save the tantalum lamp, and that is the one important point I want to emphasize. The enormous advantage of the drawn wire tungsten lamp over the fused type is not due to the drawn wire as a wire but to the type of construction which it permits—the continuous one piece filament.

There is just one other point I wish to touch upon which was brought out by one of the previous speakers, who I understand claimed an advantage for the shorter spider and increased number of anchors now used by some manufacturers in the drawn wire lamp. There is room for a difference of opinion on this point. The loss through the conduction of heat away from the filament through the additional anchor wires results at any rate in a lamp of less usefulness than an otherwise similar lamp having a fewer number of anchors.

Mr. F. A. Vaughn:—I wish to draw particular attention to the reference in the paper, and in the discussion, to small wattage and small sized lamps. In a retrospective view of tungsten lamp development up to the present state, I think we will all agree that a certain impediment has been encountered in the progress toward a general adoption of the lamp by consumers, due to the close approach on the part of the manufacturers, to the limit of their ability to make low-wattage lamps. Now again, there are some hopes, I believe, on the part of the manufacturers that they will soon be able to make smaller wattage lamps than the 25-watt size, which was more or less criticisable, perhaps, in the former development. What we illuminating engineers wish particularly in regard to the new sizes of lamps is to be imbued with confidence in the various sizes, from the highest to the lowest wattage. Most of us I think appreciate, as Mr. Howell has suggested we should, the desirability and the good qualities of the large sized units. However, a note of caution, in my opinion, ought to be sounded before the sizes smaller than the 25-watt are put upon the market; at least, I think we ought to have confidence in those smaller sizes. I, for one, am open to the injection of that confidence if Mr. Randall, or anyone else, can give us favorable data in regard to the ruggedness and desirable qualities, aside from low consumption, of very small units. As illuminating engineers, we will sooner or later, have to include or exclude in our specifications these small sizes, as the consumer naturally desires the very small wattages, he having in mind only, or principally, a reduction of his lighting bill; and this condition will exist at least until we have succeeded in educating him to some higher plane of illuminating engineering.

Mr. J. E. Randall, (in reply):—I will attempt to mention some of the points that were brought up, but will not speak in reply to any, except Mr. Howell's criticism. Mr. Howell's criticism is well made if the figures given on the first page of the paper were taken to indicate the history of the quality of any particular wattage lamp. However, the object in presenting this table is this: to show that the incandescent lamp industry needed some new development in the way of incandescent lamps in order to advance as it should. This table shows the weighted quality for all kinds of carbon filament lamps and an in-

vestigation of the data from which it has been compiled will show that any sag in quality has been due to the increased demand for extremely high wattage lamps. The demand for low wattage lamps came from two causes: one, the effort of the central station to increase its lighting business by recommending low candle-power lamps to customers complaining of high current bills: the other, the growing use of the electric sign. Now, I think that those who are familiar with carbon filament lamps will agree with me that the low wattage lamp is not as good in quality as the 50 or 60 or even the 100 watt lamp. Therefore, the large proportion of the 25, 20 and 10 watt carbon filament lamps that was supplied from 1904 to 1909 has had its effect in causing average quality to decline. Incandescent lamp manufacturers were simply going down hill while they were doing the best that they knew how. There was no indication that they would start up again, although the 50-watt and 60-watt lamps, and even the 25-watt lamps were improving in quality. I want to say right here that the people who were responsible for the work in improving the carbon filament lamp have done about the noblest work in the incandescent lamp industry that has ever been done and they have received the smallest return from the increase in the quality of the lamp. The progress was slow, certainly not encouraging. This table therefore shows the state of affairs that was being approached and which would have been reached, had not some new developments in incandescent lamps been brought out. The Gem lamp was introduced and made a wonderful progress. It had the advantage of the special work and the effort that was being put forth in improving the regular carbon filament lamp, but the range in its wattage was not great enough to cover successfully either the low or the high wattage field.

The introduction of the tantalum lamp did not greatly improve conditions, because its wattage range was not great enough in the direction of extremely low wattages. It was evident, therefore, that something entirely new was needed to change the trend of quality. This new thing was the tungsten filament lamp. It was so much superior to any other lamp that had been developed that even though it was necessary to construct special

apparatus and to arrange special wiring in signs, these changes were quickly made and to-day the tungsten filament sign lamp has almost entirely displaced the carbon filament sign lamp, with the result that the average quality of carbon filament lamps is again rising and rising rapidly.

Mr. Howell mentioned the table on the last page of my paper. This table pretends to be nothing but an illustration of one way of indicating the progress of the incandescent lamp. Remarkable improvements have been made in the last few years, many of which were necessary to the success of the lamp; but after all, the chief element in the lamp, the one that controls its quality, is the filament; and therefore, the prime feature is the temperature at which the filament can be operated with a certain result. It therefore seems to me that one may leave out of consideration the cost of power. In making the comparison which I wish to make, I endeavored to eliminate every variable that could be omitted. After all, the cost of power and the cost of electrical energy distributed to the user of lamps is an engineering problem determined for each particular installation. It may influence a decision as to the kind of lamp that should be used, but it cannot be introduced into a discussion of the development of the incandescent lamp. The cost of a lamp is not, and I believe should not, be considered in such a comparison. It is conceivable that the carbon filament lamp might cost to-day just as much as the highest priced tungsten filament lamp. That fact would affect the availability of the carbon filament lamp for certain purposes, but would not affect its real quality. Of course, the cost of manufacturing the carbon filament lamp is much below that of the tungsten filament lamp, because years have been spent in the development of the carbon filament lamp; but I hope to see the day when the cost of producing a tungsten filament lamp will be as low as the present cost of the carbon filament lamp. I have at the present time no evidence that it will, but concerted efforts are being made not only to improve the quality of the metal filament lamp, but also to reduce its cost.

It may be that the figures presented tend to handicap the metal filament lamp, but I think that the metal filament lamp

stands sufficiently ahead of the others to be somewhat handicapped and yet be well ahead in the race. I therefore believe that the comparison which I have made is a fair one for the man who is trying to improve the product of the lamp industry, because the comparison comes down to the basis of what I have called the wasted energy. I always keep the idea in front of me that the incandescent lamp as an energy transformer is exceedingly wasteful.

Mr. Howell indicated that I could have said a good deal more about the quality of the drawn wire tungsten lamp. I know I could, but the lamps have been out for several months, and I think they speak for themselves. I will affirm everything Mr. Howell has said about the good qualities of the drawn wire lamp. Besides that, you have just seen a demonstration showing how mechanically strong is the filament structure in the drawn wire lamp. I should not have dared to attempt such a demonstration as has just been given before you and yet I knew that it could be done. I hadn't any doubt about it.

Regarding the range in the wattage of the drawn wire lamp, I believe so far as the wire is concerned, that if the die manufacturers could make a smaller die, the wire could be drawn through it. I believe that a piece of wire could be drawn through a hole 0.0001 inch in diameter if the die manufacturer could make a hole that small.

The serious question about the very low wattage lamp (I refer to lamps of standard voltages) is its fragility. Experience has shown that when a very small size of wire is used in the lamp structure, the lamp is not hardy, and this characteristic is what will probably control the low limit of lamp wattages of standard voltages. I expect some improvement in this feature, but do not feel that much encouragement can be offered at the present time, because the present 25-watt lamp is not as hardy as the 40-watt, nor is the 40-watt as hardy as the 60-watt. Of course, if the lower range of voltages is considered, perfectly satisfactory lamps can be made of wattages as low as 5 or even 2, that is, the quality of the wire is equally good whether the size is suitable for 6.6 amperes or whether suitable for 0.2 ampere; but I do not believe that wattages below 25 within the

standard range of voltage are likely to give satisfactory service, except under special conditions. There is no question but that the small wattage drawn wire lamp could be made if such a lamp were demanded, but it does not seem advisable to make it at the present time and possibly not in the future.

I might mention finally that the drawn wire permits the manufacture of innumerable styles and kinds of the smaller sizes of lamps. For instance, the new automobile electric head light is an illustration. It seems to me that in a few years we will have no more gas head lights on automobiles and this condition will have been brought about by the development of the drawn tungsten wire.

PHOTOMETRY OF LARGE LIGHT SOURCES.[1]

BY G. H. STICKNEY AND S. L. E. ROSE.

The purpose of this paper is to present some of the particular features involved in the photometry of large and powerful light sources, and to describe briefly some methods and elements of photometric construction which have been successfully applied in the illuminating engineering laboratory of the General Electric Company.

The material is drawn mostly from the experience of the authors in connection with that laboratory, under the direction of Mr. W. D'A. Ryan. This experience dates back to 1898, when Mr. Stickney became associated with the work. At that time the laboratory had been in operation several years. Since then there has been a gradual improvement in instruments and methods. It has been necessary to design, construct and operate a number of photometers for the measurement of practically every type of artificial illuminant in common use. In the photometry of large units, the work has, in a large degree, centered around the development of the different forms of electric arc lamps and the application of suitable reflectors to adapt them to the requirements of the various fields of lighting. Developmental tests have also been made in connection with adapting reflectors to incandescent lamps, especially lamps of the tungsten filament type.

With the removal of the laboratory from Lynn to Schenectady in 1909 came the opportunity to build an entirely new equipment, embodying the previous experience and adapting the apparatus more particularly to the characteristics of the new illuminants which had been developed in recent years.

TYPES OF PHOTOMETERS.

There are two principal types of photometers: namely, those in which the mean spherical candle-power is observed at a single reading and those in which the intensity in any particular direction is read.

The mean spherical photometers have the advantage of sav-

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

ing time in the determination of the mean candle-power and, on this account, often give a more accurate indication of this value for a particular condition or a short period of time. In the work of this laboratory, however, the distribution of light, as well as the mean spherical intensity, has been considered of prime importance; so that the distribution type of photometer has been used almost exclusively, the mean spherical intensity being calculated from the determined values. All the photometers described in this paper are of the distribution type.

Distribution photometers are commonly built in three different forms: namely, the constant length, constant intensity and constant radius photometers.

The constant length photometer is the oldest form in common use and is the simplest to construct. As the name implies the length of the photometric axis is constant and measurements are made by varying the position of the photometer disk between the standard and the light to be measured.

In the constant intensity photometer, the distance from the standard to the photometric screen is fixed and the distance, between the two and the light to be measured, is varied until the balance is obtained. This maintains the intensity on the photometer screen at a fixed value, which gives particularly accurate results for the class of readings to which this type of photometer is adapted. This type of photometer is used to a considerable extent in the Bureau of Standards at Washington.

In the constant radius photometer the distance between the light to be measured and the photometer disk is retained constant, while the distance to the standard is varied. This arrangement is particularly advantageous where the measurements are to be made on lamps equipped with reflectors or otherwise having a large area; so that there is more or less question as to how far the law of inverse squares will apply. When this point is in question, the readings are designated as "apparent candle-power" at the distance for which the photometer is set. The actual mean spherical candle-power or total flux of light can be calculated from the apparent candle-power thus obtained. On account of this advantage, this form of photometer has been used almost exclusively in the laboratory for the past six or eight years.

There are a number of methods for directing the light to the photometer disk; for example, in an instrument which has been used for a number of years at the Massachusetts Institute of Technology the entire photometer was pivoted at the photometer disk on a horizontal axis perpendicular to the photometric axis. The light unit to be measured was suspended at one end of the bar so as to retain its vertical position with the center of illumination at a fixed distance from the disk. The standard was mounted upon a track at the opposite end of the bar so that it could be controlled from the photometer disk. This photometer belongs in the constant radius class. Its radial distance is ten feet. The arrangement was such that the light from any angle with reference to the test lamp could be measured directly on the photometer screen without the use of any mirrors.

Another ingenious constant radius photometer is in the Electrical Testing Laboratories, New York.[1] In this photometer the disk is attached to the end of an arm and swung in a vertical plane around the lamp to be measured. The intensity of illumination on the disk is measured with the Sharp-Millar photometer, the light being reflected into the instrument by means of a mirror mounted on the axis of the arm.

An interesting form of photometer[2] was used by Professor Matthews in the arc lamp tests at Purdue University for the National Electric Light Association. In its original form, a ring of mirrors was arranged around the lamp to be measured perpendicular to the photometric axis. The mirrors were adjusted so as to reflect the light from the various angles of elevation on the photometer disk. This photometer could be used as a distribution photometer by covering all the mirrors, excepting one or two at the elevation at which it was desired to make the measurement. The mean spherical candle-power was read by exposing all of the mirrors but coating them with an absorbing film to introduce the cosine factor. Considerable difficulty was experienced, however, in securing an accurate coating, and this was later improved in accordance with a suggestion by Dr. Steinmetz, whereby the absorption was obtained by a suitable screen inserted in front of the photometer disk.

[1] For description, see lecture by C. H. Sharp, "*Measurement of Light*," in Lectures on Illuminating Engineering, (Johns Hopkins University, 1910), vol. I, p. 474.

[2] Described and illustrated on p. 474, vol. I, Lectures on Illuminating Engineering (Johns Hopkins University, 1910).

A similar form of photometer, used by Blondel and later by Professor Matthews, had but two mirrors, pivoted and swung around the photometric axis. It was similar in principle to the twin-mirror photometer now in use in the Schenectady laboratory, which is more fully described later on in this paper.

Another photometer embodying the Dibden principle has been designed primarily for the testing of lamps used in connection with large diffusing or reflecting surfaces up to six or eight feet in diameter. It has not been built or installed up to the present time although suitable space has been reserved for it in the Schenectady laboratory. Tracks run the full length of the room along the side walls about midway between the floor and ceiling,

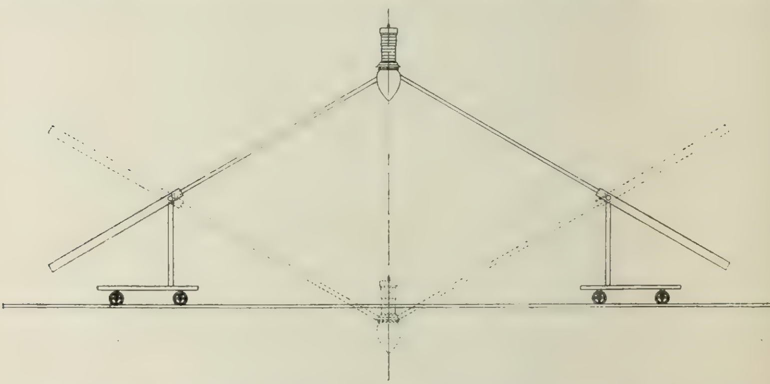


Fig. 1.—Elevation diagram of constant radius photometer (traveling crane type).

and supports two carriages similar to traveling cranes, one on each side of the lamp to be tested. On these carriages a photometer disk, standard lamp and seat for an observer are mounted as indicated in fig. 1. The lamp to be tested is suitably suspended and tied to each carriage by arms so that as the lamp is raised or lowered the carriages run forward or backward, always keeping the photometer disk at a distance of ten feet from the center of light. Simultaneous readings are taken on both sides of the lamp.

A photometer which was used at Lynn to accomplish similar results is shown diagrammatically in fig. 2. The unit to be tested was suspended with its center of illumination on a horizontal axis about which two arms, one on each side of the room, were rotated. Each arm carried a small photometer and the observer, who propelled himself about the lamp by means of a hand-wheel

and suitable gears. Simultaneous readings were made on both sides of the lamp.

In this laboratory, however, practically all the measurements have been made with two forms of photometer: namely, the single-mirror crane type photometer and the twin-mirror photometer. Four photometers of the crane type were erected and used successively when the laboratory was in Lynn. The last

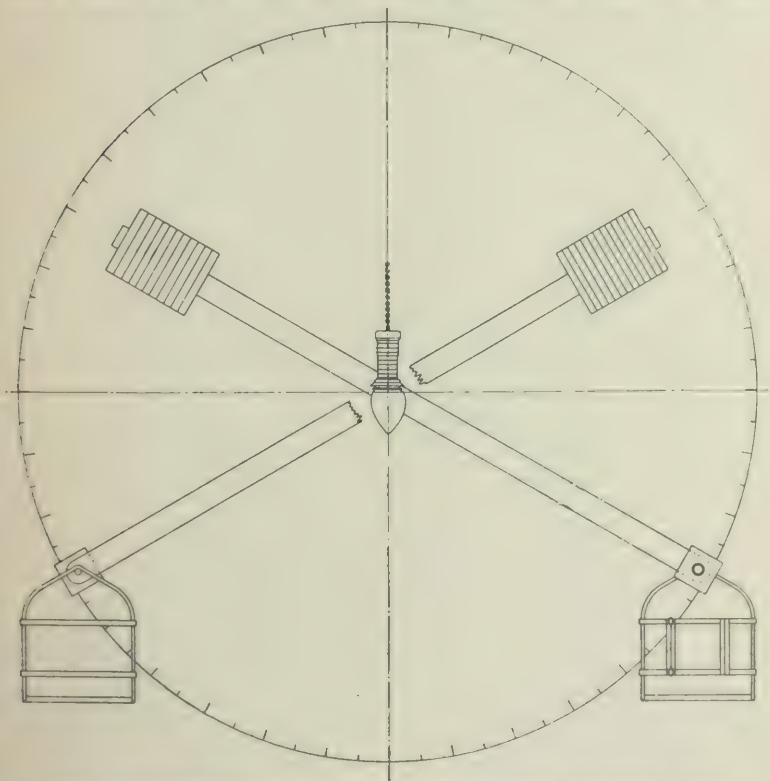


Fig. 2.—Elevation diagram of constant radius photometer (rotating arm type).

one, which was built about 1907, is illustrated in fig. 3. In this photometer the sight box was supported on a stand at a fixed point and suspensions were arranged on the crane so that tests could be made at a radii of either ten or fifteen feet. The track carrying the standard lamp carriage was supported from the ceiling. A partition, with only a small opening on the photometric axis, prevented any direct or stray light from the lamp

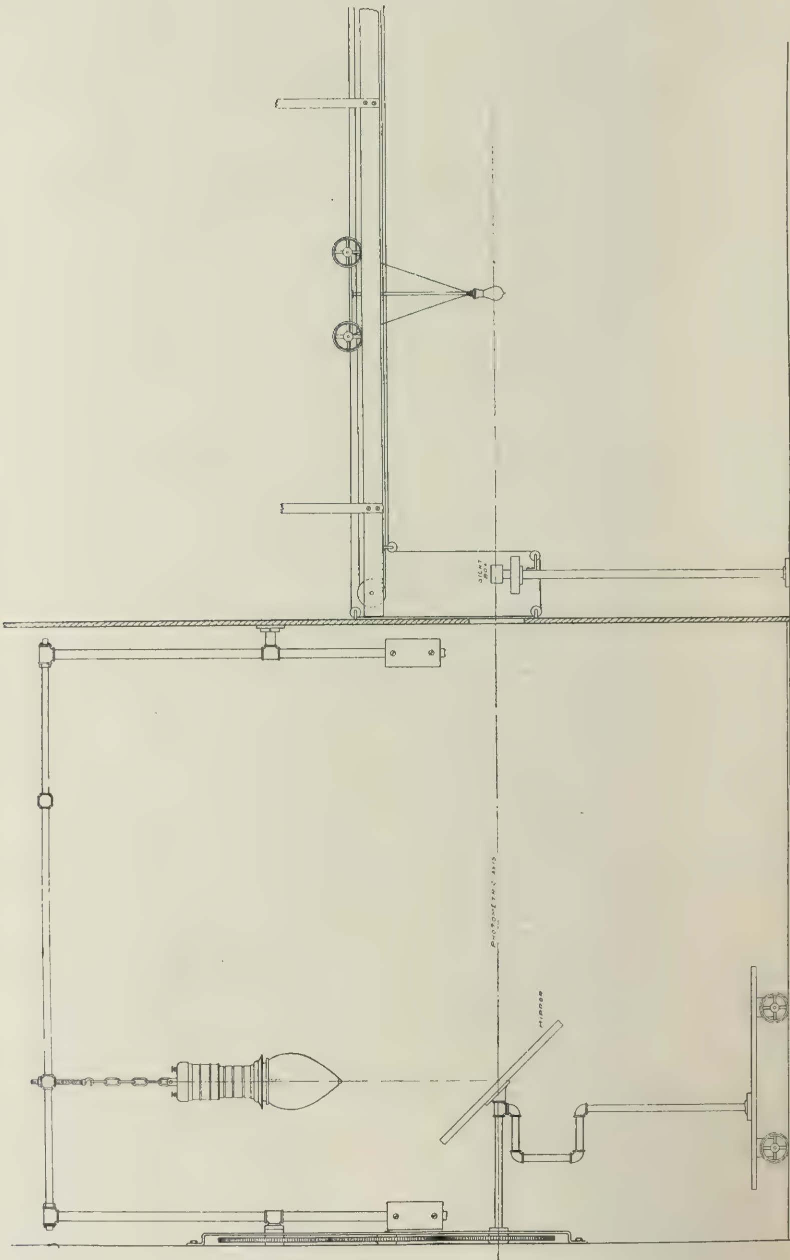


Fig. 3.—Elevation diagram of single-mirror crane type photometer at Lynn laboratory of the General Electric Company.

under test reaching the sight box. The standard lamp carriage was motor driven and controlled by a suitable switch near the sight box. Trouble was experienced in stopping the carriage quickly and this was later changed to hand-control. An improved crane type photometer for small units is now in use at the Schenectady laboratory.

When the laboratory was transferred to Schenectady in 1909, the twin-mirror photometer was adopted for the larger unit work. This photometer employs two mirrors mounted on arms which rotate about the photometric axis. Thus the centers of the mirrors are retained in a vertical plane perpendicular to the photometric axis at the center of the light source. The mirrors are set at such angle as to reflect the image of the light source

Fig. 4.—Plan diagram of twin-mirror photometer, showing arrangement of test lamp and mirrors.

on the photometric disk. This is shown diagrammatically in fig. 4. The elevation sketch in fig. 5 shows the mechanical arrangement of the photometer.

The overhead track with suspended carriages is hung from the ceiling. This construction has the following advantages over the ordinary type. Track reflection is more easily eliminated. The room is not blocked up. The alinement can be easily arranged for accurate adjustment.

The total length of the room is approximately forty feet and the width fourteen feet. The height varies from about twelve feet at one end to eighteen feet at the other. The length of track is about twenty-four feet. The photometric axis is approximately five feet three inches above the floor. The whole interior is painted a dull black. Suitable screens are used to prevent any reflected light from walls, floor or ceiling, or any

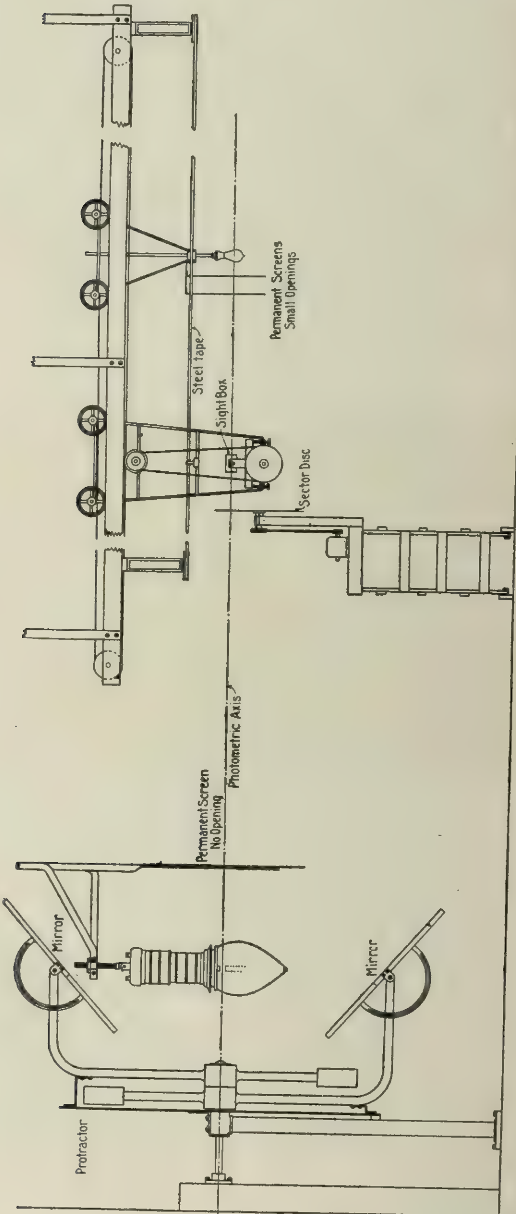


Fig. 5.- Elevation of mechanical arrangement of twin-mirror photometer. (Mirrors in vertical positions to show methods of mounting.)

other stray light, striking the disk of the sight box or the eyes of the observer. The screen which cuts all direct light from the photometer disk is supplemented by a number of portable screens arranged so that they can be readily adjusted for the various conditions. A Lummer-Brodhun contrast type sight box is mounted on a carriage suspended from the photometer track. Ordinarily this is securely fastened at a point which gives a photometric radius of twenty feet. The arrangement, however, is such that this radius can be changed within certain limits to suit requirements. Both the sight box and the working standard lamp are provided so that they can be adjusted vertically in case realinement of the track becomes necessary. The working stand-

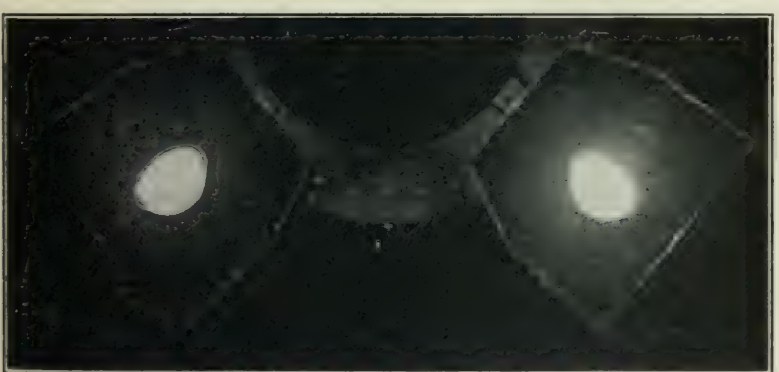


Fig. 6.—Photograph of twin-mirrors set at 50 degrees from vertical axis. (Viewed from photometer screen.)

ard is moved back and forth in securing a balance by means of a belt mechanism operated by the observer through a hand-wheel situated below the sight box.

A steel tape, graduated in feet and tenths, passes around a pulley at each end of the track and is securely fastened to the lamp carriage. A pointer in front of the observer indicates on the tape the distance between the standard lamp and photometric disk for each setting.

The mirrors are large enough to accommodate a lamp with a reflector over three feet in diameter. Fig. 6 shows a testing position, both mirrors being set at 50 degrees from the vertical axis. Fig. 7 shows another testing position with the mirrors set at 110 degrees from the vertical axis. These photographs were

taken with the lens of the camera at the point that the disk of the sight box occupies during the test. The large metal protractor for indicating the elevation of the mirrors can be seen, the screen having been removed in order to show it.

The sector disk is mounted on a portable stand arranged for vertical adjustment, which not only facilitates the changing of its position from one side of the sight box to the other, but also prevents any vibration from the rapidly rotating disk being transmitted to the photometric apparatus. A single disk, driven by a small motor has been used in preference to the adjustable disk because of its simplicity and accuracy of calibration. Using a sector disk with a ratio of approximately 6 to 1, candle-powers ranging from 12,700 down to 6 have been satisfactorily

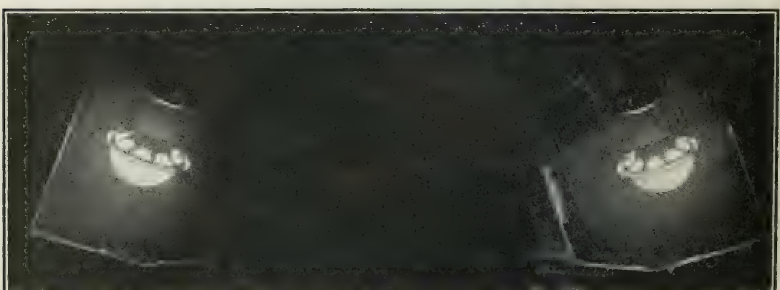


Fig. 7.—Photograph of twin-mirrors set at 110 degrees from vertical axis. (Viewed from photometer screen.)

measured. By using a disk of higher ratio, an even wider range could be secured. The desirability of providing for so large a range is indicated by some of the recent tests: for example, a flame arc lamp gave, at its angle of maximum intensity, an average of over 3,000 candle-power, and at its angle of minimum intensity, an average of slightly less than 100 candle-power. In another test on projector arc lamps a candle-power intensity of over 12,000 was readily measured with this photometer.

STANDARD LAMPS.

Three classes of candle-power standards are used: namely reference standards, substitution standards and working standards.

Reference standards consist of carbon incandescent lamps with a parallel type filament furnished by the Electrical Testing Lab-

oratories of New York City and verified by the Bureau of Standards at Washington. New reference standard lamps are purchased at frequent intervals and interchecked with the older ones and with each other. These lamps are burned for only very short periods of time, and great care is taken not to apply a higher voltage than called for on the calibration.

Substitution standards consist of 250-watt or other high candle-power multiple tungsten lamps, carefully seasoned and checked against two or more reference standards and against each other, without the use of mirrors. The mirrors and working standard lamps are calibrated at the same time by placing a substitution standard lamp in the photometer the same as any other lamp to be tested.

Working standards consist of 40-watt multiple tungsten lamps of special design furnished by the Electrical Testing Laboratories. These are checked against the substitution standards. Calibration tests are made frequently—at least once a week, and, in some cases, daily. When the standards show any discoloration or change in candle-power they are discarded.

A careful check has been made of the results obtained by different observers and also with other laboratories. It is advisable to do this as often as possible in order to prevent the creeping in of errors in readings or methods. It has, for some time, been the custom to check, from time to time, measurements of the so-called "arc lamp" or "large unit" photometer with the so-called "incandescent" or "small unit" photometer. This has been done by testing a tungsten filament lamp in both photometers. As these photometers are built on different lines, this tends to eliminate any local errors.

METHOD OF TEST.

The lamp to be tested is hung so that its center of illumination is, as near as possible, in the photometric axis. The lamp is then connected to the supply circuit and suitable meters inserted to give the necessary measurements of power, pressure, etc. Curve drawing meters are used to give a continuous record of volts, amperes or watts. Each lamp is warmed by a preliminary burning until it reaches a constant condition before a final check is made of its adjustment and the photometric test started.

For all ordinary tests, lamps are operated under standard conditions and as near as possible at their commercial ratings. It is impracticable to operate all types of lamps at a constant adjustment, owing to instantaneous variations of longer or shorter

GENERAL ELECTRIC COMPANY, SCHENECTADY, N Y
ILLUMINATING ENGINEERING LABORATORY

Testing Record **INCANDESCENT LAMP** Test No.________

TO BE USED FOR ORIGINAL READINGS AS TAKEN DURING TEST AND RETURNED TO ENGINEERING DEPT.

Apparatus________

Special Features________

REQUEST NO.______
CURVE NO.______
PHOTOM. NO.______
RADIUS______
STAND. LAMP NO.______
VOLTS STD. LAMP______
C. P. STD. LAMP______
CONSTANT______

CONFIDENTIAL—Property of GENERAL ELECTRIC COMPANY, for information of employees only.

PHOTOMETRIC READINGS

DEGREES FROM VERTICAL AXIS

	0°	10°	20°	30°	40°	50°	60°	70°	80°	85°
AVER										
C P										

DEGREES FROM VERTICAL AXIS

	90°	95°	100°	110°	120°	130°	140°	150°	160°	170°
AVER										
C P										

A.C.-D.C.-MULT. SERIES
CYCLES
AMPERES
VOLTS
WATTS
HRS. BURNED
MEAN HOR. C.P.
REFLECTOR
DIFFUSER
SHADE
HOLDER
FILAMENT DISAPPEARS
GLOBE DISAPPEARS

Remarks:

P. Observer______
I. Observer______
Calc. by______
Checked by______
Date______

Fig. 8.—Record sheet for incandescent lamps.

duration. In such a case, narrow limits are assigned and photometric readings made only when the lamp is operating within the assigned limits. No definite rule can be set as the range of these limits may vary for different types of lamps. A number

of photometric settings are made by different observers every ten degrees throughout one or more vertical planes, starting at a point directly beneath the lamp.

After a careful investigation, the use of automatic record-

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.

Testing Record

GAS LAMP

Test No.

TO BE USED FOR ORIGINAL READINGS AS TAKEN DURING TEST AND RETURNED TO ENGINEERING DEPT

Apparatus

Special Features

REQUEST NO

CURVE NO

PHOTOM NO.

RADIUS

STAND LAMP NO

VOLTS STD LAMP

C P STD LAMP

CONSTANT

CONFIDENTIAL. Property of GENERAL ELECTRIC COMPANY, for information of employees only

PHOTOMETRIC READINGS

DEGREES FROM VERTICAL AXIS

0°	10°	20°	30°	40°	50°	60°	70°	80°	85°

AVER.

C P

MANTLES

GAS PRESSURE

CU. FT. PER HR

QUALITY

HRS. BURNED

GLOBES

REFLECTORS

SHADES

MANTLE OR FLAME DISAPPEARS

GLOBE DISAPPEARS

DEGREES FROM VERTICAL AXIS

90°	95°	100°	110°	120°	130°	140°	150°	160°	170°

AVER.

C P

Remarks:

P. Observer

I. Observer

Calc. by

Checked by

Date

Fig. 9.—Record sheet for gas lamps.

ing devices has been abandoned, it having been found preferable to have the values called off by the photometrist and recorded by the observer in charge of the electrical instruments, meters, etc. This was found to avoid confusion in throwing out

readings taken when the lamps were not operating under rated conditions.

Nearly all illuminants measured give an approximately sym-

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.
ILLUMINATING ENGINEERING LABORATORY

Testing Record **ARC LAMP** Test No.______

TO BE USED FOR ORIGINAL READINGS AS TAKEN DURING TEST AND RETURNED TO ENGINEERING DEPT.

Apparatus______

Special Features______

EQUEST NO.______
CURVE NO.______
PHOTOM. NO.______
RADIUS______
STAND. LAMP NO.______
VOLTS STD LAMP______
C. P. STD. LAMP______
CONSTANT______

CONFIDENTIAL—Property of GENERAL ELECTRIC COMPANY, for information of employees only.

PHOTOMETRIC READINGS

DEGREES FROM VERTICAL AXIS

	0°	10°	20°	30°	40°	50°	60°	70°	80°	85°
AVER.										
C P										

DEGREES FROM VERTICAL AXIS

	90°	95°	100°	110°	120°	130°	140°	150°	160°	170°
AVER.										
C P										

A.C.-D.C.-MULT.-SERIES
CYCLES
AMPERES
VOLTS TERM.
VOLTS ARC
WATTS TERM
WATTS ARC.
HRS. BURNED
GLOBES
INNER
OUTER
REFLECTORS
DIFFUSERS
SHADES
ELECTRODES
UPPER
LOWER
ARC. DISAPPEARS
GLOBE DISAPPEARS

Remarks:

P. Observer______
I. Observer______
Calc. by______
Checked by______
Date______

Fig. 10.—Record sheet for arc lamps.

metrical distribution of light; that is, practically the same candle-power is emitted in all directions with respect to the vertical. This, of course, represents the simplest case in which the candle-power measurements in a single vertical plane represent the values for all directions. Where the distribution of light is un-

symmetrical, readings are made in three or more critical or intermediate planes, depending upon the amount of variation and its character. In such cases it is customary to plot several

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.
ILLUMINATING ENGINEERING LABORATORY

SPHERICAL CANDLE POWER DATA Test No. ____

Apparatus ____ | Request No. ____ | Curve No. ____ | Date ____

LOWER HEMISPHERE			
Degrees from Vert.	C P	Constant	Volts Term.
0		.00381	Volts Arc.
10		.0302	Amp.
20		.0596	Watts Term.
30		.0872	Watts Arc.
40		.112	Enc. Globe
50		.133	Outer Globe
60		.151	Reflector
70		.164	Holder
80		.172	Circuit
90		.0872	Frequency
			Electrodes
			Mean Lower Hem. C.P
UPPER HEMISPHERE			
90		.0872	Watts per M.L.H.C.P. =
100		.172	M.L.H.C.P. per Watt =
110		.164	Watts per M.S.C.P. =
120		.151	M.S.C.P. per Watt =
130		.133	Total lumens =
140		.112	Downward lumens =
150		.0872	Total lumens per Watt =
160		.0596	Dwn'd lumens per Watt =
170		.0302	Mean Hor. C.P. =
180		.00381	Watts per M. Hor. C.P. =
			Mean Upper Hem. C P.
			Mean Spherical C.P.

Remarks ____ | Calc by ____ | Checked by ____

Fig. 11.—Final data sheet.

curves and also a mean curve. For curves representing types of lamps, tests are made on a sufficient number of electrodes, mantles or other parts to eliminate individual variation and the tests averaged to obtain the mean curve.

The sheets for recording the original readings taken during

the test and the final data sheet from which the curve is made and the hemispherical and spherical candle-power calculated are shown in figs. 8, 9, 10 and 11. These are self-explanatory. For irregular curves, where the variation of candle-power from angle to angle is rapid, the mean spherical and hemispherical candle-power values are obtained by means of a Rousseau diagram and planimeter. Wherever possible, however, the calculation method is used, since it is quicker and less liable to introduce personal errors which are difficult to discover.

ELIMINATION OF ERRORS.

The following are some of the more important details to which too much attention cannot be paid in order to eliminate all possible sources of error, both in calibrating and testing. A sufficient number of screens and proper placing of them to prevent stray light from reaching the disk in the sight box or the observer's eyes should be provided. Especially where very powerful lights are to be measured, it is important to watch every possible source of stray light. Even dull black surfaces may reflect sufficient light to affect the results when illuminated to a very high intensity. Photographs taken from the position of the photometer disk are of assistance as a final check in eliminating such discrepancies. The sight box and standard lamp should be kept as free as possible from vibration. All meters should be carefully calibrated: for example, a one per cent. error in voltage may result in a five per cent. error in candle-power or even more. Meters of proper capacity should be used, *i.e.*, one should not try to measure five amperes on a thirty-ampere meter. If possible, meters of such capacity that the needle is about the center of the scale should be used. For alternating-current work, the proper frequency should be held constant during the test. All distances should be measured with an inextensible scale, such as a steel tape. A large error in candle-power may be introduced by measuring distances with a linen tape which has become stretched, or other scales which have become distorted. Standard lamps must be accurately set up; when stationary, a certain definite position with relation to the photometric disk must be maintained. Pressure leads must be extended direct from the voltmeter or wattmeter to the point at which it is de-

sired to measure the voltage. Mirrors of the best quality of crystal glass and the thinnest plate must be used. They must be kept clean and free from scratches or other imperfections. Readings must be taken only when the lamp is operating at correct adjustment. If necessary, the lamp should be readjusted and the test started over again. In any photometer in which the light strikes the disk at a perceptible angle, care must be taken to make sure that the relation of the angle of view in the sight box does not affect the results.

Practically all large light sources must, for mechanical reasons, be operated in a vertical position. Very few of them can be rotated without affecting their operation. This must be allowed for in the design and operation of the photometers. Especially if the area of the source is large, or if it is provided with reflectors so designed that there are one or more virtual light sources, it is desirable that the distance to the photometer disk should be as great as possible in order to minimize any errors due to the variation from the point source of light or discrepancies in locating the center of illumination. The size of the photometer is usually limited, however, by the space available and, with some forms of photometer, by the mechanical construction required.

CHARACTERISTICS OF LIGHT SOURCES.

Proper consideration should be given to the requirements of the various lighting units. The photometer must be designed to accommodate conveniently the mechanical, as well as the luminous characteristics of all the various light sources likely to be measured. The clearances must be sufficient to allow for various mechanical constructions, and the lamp suspension must be so arranged that the center of illumination of the lamp can be adjusted to the proper point on the photometric axis.

The real difficulties in the photometry of large units are those introduced by the variation in color and intensity of the light. Of these two, the variation in intensity is usually the principal source of error in measurement, and tests the judgment of the photometrist in assigning a fair value. Many large light sources are subject to changes in intensity. The light may vary more or less regularly and with longer or shorter periods. In some

cases it is complicated by a wandering of the maximum light in various directions about the lamps. Variations which would hardly be noticeable to the ordinary observer make the reading of a photometer much more difficult. It is not uncommon to find readings varying from twenty per cent. of the mean to three hundred per cent. An especially trying example is one of the forms of flame arc lamps which, for a period of time, gives a powerful yellow light and then, for another period of time, a weaker orange light. The question arises as to which value should be taken. For want of a better method of approximation, readings have been taken over a period of time sufficient to give a fair weight to each condition of burning and the average value determined. This is not entirely satisfactory, since the value of the light is not so great as that of a steady light of the same average intensity. On the other hand, particularly where the lamps are operated in groups, it is considerably above the minimum. Several years ago this situation was further complicated by the fact that, before the days of careful photometry, excessive candle-power values were assigned to open arc lamps, and were so thoroughly associated with them that the conception of candle-power by engineers and others was influenced by this rating. On this account, Mr. Ryan found it expedient, in 1901, to make comparisons between arc lamps in terms of the average maximum candle-power, the values being so designated.[3] Later, when it became necessary to make comparisons between arc lamps and other illuminants, the average intensity was adopted, since the average maximum values did not apply. This change was followed by the adoption of the average value of comparison between arc lamps themselves.

Where the variation in intensity is rapid, it is difficult to obtain consistent readings. An inexperienced photometrist is inclined to follow the variation and thus obtain values higher or lower than the mean, depending upon his personal habit in setting and reading the photometer disk. Two methods have been followed in the laboratory to minimize errors in this respect. In some cases the maximum and minimum intensities have been measured and the mean determined. In other cases a large num-

[3] "*The Relative Merits of Open and Enclosed Arc Lamps for Street Illumination*," a paper read before the Ohio Electric Light Association, August, 1901.

ber of sharp, quick readings have been made at regular intervals and the values averaged. It is essential that the photometric balances should be made as quickly as possible so as to obtain an instantaneous value. With excessive variation, therefore, a photometer disk which can be read rapidly may give more accurate results than a more sensitive form requiring more time. On this account, in the single-mirror photometers used at Lynn, the best results were obtained with the Bunsen disk; while on the twin-mirror photometer at Schenectady, which has a tendency to steady the light on the disk, the Lummer-Brodhum (contrast screen) was found preferable. The advantage of the Bunsen disk in the former case was due to the absence of the telescope. By reducing the variation of intensity on the photometer screen, the twin-mirror photometer has reduced the time and effort of reading and increased the accuracy. Check tests between the crane type and the twin-mirror type photometers have checked exceedingly close in the average values obtained, while the variation between the measurements of a number of observers has been considerably less with the latter.

As explained elsewhere, either the carbon or tungsten filament incandescent lamp has always been used as a working standard. The color of light from practically all other sources differs, in a greater or less degree, from that of these standards. While this difference in color makes it somewhat more difficult to make accurate settings, especially with inexperienced observers, it is surprising what facility and accuracy is attained with experience in setting the photometer. Moreover, with light sources of varying intensity, the color difference becomes almost insignificant on account of the fact that the accuracy of the readings cannot be as great as with steady sources. Some experiments were made several years ago with the flicker photometer, but partly on account of the chance of stroboscopic interference, its use was found to be inadvisable under the existing conditions.

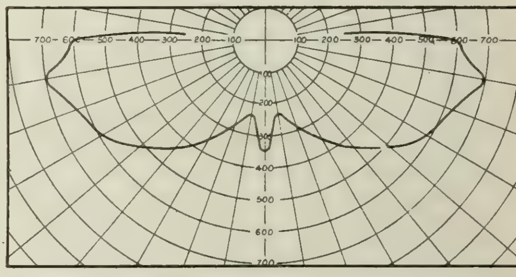
Both the intensity and the characteristic of distribution of some forms of lamps vary, from time to time during their operating life. In some forms of arc lamps, this is due to the change in the position of the arc with reference to the reflector or other parts of the lamp. In such cases it is desirable to run photometric curves at different periods during the life of the elec-

trodes, this testing being designated as the "photometric-life test." In other forms of lamps the candle-power varies rapidly for slight changes in the angle of elevation. This is generally due

LUMINOUS ARC LAMP
MAGNETITE
Direct Current Series Circut

Volts, Terminal	75-80
Amperes	4
Watts	310
Mean Hemispherical C-p	536
Watts per Mean Hemispherical C-p	.58
Mean Hemispherical C-p per Watt	1.73
Mean Spherical C-p.	294
Watts per Mean Spherical C-p	1.05
Mean Spherical C-p per Watt	.95

PHOTOMETRIC TEST
Apparent Candle-power in a Vertical Plane



Readings taken at 21.25 Ft Radius
Equipment – Standard internal concentric reflector, clear globe N° 14 and ash pan

Curve is an average of tests on nine Standard Magnetite Electrodes 5/8" dia.

Test N° 1256
GENERAL ELECTRIC CO,
Schenectady, N.Y.
April, 4, 1911
Checked by S.L.E.R.

APPROVED W. D'A. Ryan
ILLUMINATING ENGINEER
C-5976

Fig. 12.—Typical photometric curve, showing method of recording conditions and data.

to the reflecting and cutting-off effects of the reflectors. An example of this is the luminous arc lamp equipped with a street reflector, which has a high maximum candle-power at 80 deg., falling off rapidly as it approaches the horizontal. In the parts of

the curve where the variation is rapid, readings are made every two or three degrees, although in general, where the variation is less rapid, an interval of 10 degrees is maintained.

PHOTOMETRIC CURVES.

Difficulty is frequently encountered in interpreting photometric curves due to lack of data and description of the conditions of the test. Fig. 12 shows a photometric curve derived from a representative test and illustrates the practise of this laboratory. Unquestionably the reliability and usefulness of such a curve is, to a large degree, dependent upon the accuracy and completeness with which such information is given.

DISCUSSION.

Mr. P. S. Millar:—The photometers described in this paper are of interest to those who have to do photometric work on large illuminants. The photometer, the essential features of which are illustrated in fig. 1, appears to be a modified form of the Dibdin photometer, arranged for use by two observers simultaneously. I should imagine that that gives an equivalent of the twin-mirror scheme in that simultaneous observations are made on opposite sides of the lamps, and when the lamp is fluctuating, a more accurate average value is obtained.

The "ferris wheel" photometer illustrated in fig. 2 is unique. The twin-mirror scheme illustrated in fig. 4 is one which most of us who have done work of this kind have employed. I would like to ask the authors if they have made some such experiment as to place a lamp in the photometric center, attach it rigidly to one of the mirrors, and rotate the mirror throughout the 180 degrees, or preferably throughout 360 degrees, in order to observe how nearly a constant reading is obtained from the photometer under those conditions. I have in mind among other possibilities some little divergence that might be caused due to the light striking the photometric surface at various angles with that of view.

The use of the twin-mirror photometer of any type simplifies the obtaining of a fair photometric value. However, it does not always give one all the facts. I would like to ask the authors if they have ever obtained an instantaneous distribution curve

about arc lamps. Of course, if there is high value on one side of the lamp and low value on the other side of the lamp, with the twin-mirror photometer, one gets a mean value.

The statement is made that the use of the automatic recorder has been abandoned for some purposes. In my judgment the automatic recorder is almost indispensable. If a fluctuating light source is to be photometered, and one wants to arrive at a fair average value, I believe that the best method is to have the photometrist devote his entire attention to following the fluctuations in intensity. He can do this to better advantage if relieved of the neccessity of noting results. An automatic recorder enables one to do this in a manner which is satisfactory for many purposes. Of course there comes a time when the automatic recorder does not serve the purpose, because one wants to know more about the fluctuations than the ordinary automatic recorder will report. When the chief purpose is to determine what the average value is, I do not see how an automatic recorder can be improved upon.

Having visited the laboratories at Lynn and seen the very excellent equipment there installed, I want to compliment the authors on the excellent work that they are doing, and the excellent apparatus that they have devised. The only thing which seems lacking is an integrating photometer. In the manufacture of arc lamps and electrodes, it becomes necessary to determine the total flux of light given by experimental electrodes time and time again, and I think the integrating photometer is unequalled for that class of work.

Dr. H. E. Ives:—I am very much interested in one point brought out in this paper, that is, that the greatest difficulties in the photometry of large sources of light arise from variations in color and intensity. The extent of these variations has been brought out by the authors. Now, I have never had to measure a large fluctuating source of light. I can be a mere theorist on that point. But several years ago, when I was connected with the Bureau of Standards, it was planned to make a distribution photometer for measuring, arc lamps, and other fluctuating sources, and of course this question of variation of intensity and color came up. To meet that, I designed a photometer, a distribution

photometer. As far as I know, it has never been built, because the bureau has not been working along that line. But there was one detail of that which fixed itself in my mind. I have been very fond of it, and I want to get the opinion of those who have worked with these photometers on whether it is practicable, or whether it is merely theoretical. The idea is this: In the case where one merely wants distribution, and the light source is varying a great deal, why not use as the standard the light of the source itself? Let for instance the light from the radial mirror be matched always against the light coming in the horizontal direction from the lamp. If the total intensity of light goes up a few hundred per cent. not only will the light from the radial mirror do this, but the standard will do so too. Moreover the "standard" and the light measured would be of the same color. I have an idea that somehow in getting distribution curves a scheme of that sort would cut down the amount of work and increase the accuracy a great deal. Of course, it would not give an absolute measure, but it would only be necessary to make a measurement in a single direction of the absolute candle-power. Then again, as Mr. Millar suggests, why not make the measurement of the total flux with a sphere? In using the photometers which have been described a large number of uncertainties enter, due to the variation of intensity and color. This alternative method appears to be a way in which a distribution curve may be obtained independent of variations in intensity, and color. As I say, I have never tried this scheme out, and so I would value an expression of opinion by people who have tried it. Perhaps the difficulties would be altogether too great, but I would like to hear something about it.[1]

Mr. W. J. Cady:—I would like to ask the authors of this paper whether they have any data showing the errors in the testing of light sources which differ greatly in color from the standard lamp, due to the selective absorption of the mirrors. Figures have been obtained by Prof. E. F. Nichols showing that the coefficients of reflection of mirrors for lights of different colors in the visual spectrum varies from 82.7 per cent. to 95

[1] Since making these remarks at the convention of the society, my attention has been called to the fact that Matthews and later Fleming have described this method of securing distribution curves. They do not however, give any results on the use of the method with arc lamps as compared with the usual method

per cent. If, therefore, two or three mirrors are used, the addition of these errors might be quite considerable even for lamps which do not differ more in color than an arc lamp or standard incandescent lamps. Of course the variations in the intensity of an arc lamp are very much greater than the errors produced by a difference in color, but in the case of lamps which are constant in intensity but which differ considerable in color from that of the standard lamp, this error due to the selective absorption might be greater than is desirable for accurate work.

I might mention a photometer which the Holophane Company has at Newark. This is of the Dibdin type and, therefore, does not require the use of mirrors. In this photometer the test lamp is moved in a vertical line, and the comparison lamp and photometer head in a horizontal line, a fixed distance between the test lamp and photometer being maintained by connecting rods. This particular photometer was designed and built and then the building built around it, as it is so large as to reach through three floors. such a photometer requires a careful analysis of the usual drawbacks to the Dibdin photometer. One of the drawbacks is the screening system and the other the angle setting device. The screening is taken care of in this particular instrument by placing an adjustable screening cylinder around the photometer head and the angle setting by measuring the angles at both the photometer head and the test lamp.

Mr. W. F. Little:—In figs. 6 and 7 of the ninth and tenth pages of the paper decided bright streaks are noticeable around the mirrors. There streaks are even more noticeable on the lantern slide. Mention is made of a screen having been taken away to show the protractor. Would this screen, if left in place, prevent the stray light from a mirror edges reaching the photometer disk.

The method of test for arc lamp distribution measurements employed by the Electrical Testing Laboratories is to take from 100 to 1,000 quick readings over a period of 3 to 10, or even 15 minutes, using a Leeson disk, recording the readings automatically so that the operator is not obliged to look at anything but the disk during the test. In a fluctuating source such as an arc lamp, it is believed that "quick snap" readings as referred to by

the author, are preferable to slow studied readings. A lamp is started an hour or so before test, and its operation studied, so that during the test, measurements are made without interruption, unless the observer watching the electrical instrument finds that some abnormal condition exists, in which case photometric measurements are suspended until the lamp is operating normally. However, in the majority of instances, no interruption is made, but frequent checks are taken to secure values more nearly approximating the true mean. To represent the actual operation of the lamp during test, the mean of all measurements, the mean of the maximum ten and the minimum ten are given.

The authors state that they secure better results with the Lummer-Brodhun photometer than with other types. Experience at the laboratories indicates that the Leeson disk is quicker and less tiresome, and perhaps quite as accurate as the Lummer-Brodhun for this purpose, probably due to the fact that the operator can use two eyes and is not compelled to look through a telescope.

The authors seem to have had difficulty in the use of the flicker photometer with alternating-current lamps, due to stroboscopic effect, yet they make no mention of this difficulty with the rotating sector disk. Will a simple change of speed eliminate all errors of this character?

Does not stray light militate against accuracy to the same degree in the case of small as well as in powerful light sources? This is referred to on the sixteenth page of the paper.

Mr. R. B. Hussey:—I think Mr. Rose has covered very well the outfit and the procedure followed at Lynn, as well as at the laboratory in Schenectady.

In regard to Mr. Millar's remarks concerning the outfit referred to on the fifth page of the paper, I may say that this was developed with the idea of handling very light sources, where the source of light including reflector is so large that it can not be raised and lowered, and where one can not consider the results as being candle-power, but merely illumination at that particular distance. The outfit was somewhat awkward and clumsy and has not been used to any great extent.

Referring to page 659: most of my work has been done with the single mirror in place of the twin-mirror, and although I

feel that there is some advantage to be gained by the use of the twin-mirror, nevertheless, for the use with the ordinary modern forms of high intensity lamps, such as flame carbon arc lamps, and the luminous (magnetite) lamps, this difference is somewhat less than would be inferred from Mr. Rose's paper. The variations of intensity in this type of lamp seem rather to be variations in the total flux than changes due to the position of the arc, so that from a single mirror nearly the same results will be obtained as from two. At the same time I think there is some advantage in steadiness to be obtained from the two mirrors.

I agree, also, with Mr. Little in regard to the cause of the photometer screen. I have been using almost entirely the Leeson disk type for the same reasons that Mr. Little mentioned. It seems to be easier on the eyes, because of its being a two-eye rather than a single-eye outfit. I believe, too, the differences in color are more easily handled, if they must be handled quickly as they must with these arcs, by using the Leeson disk, than with the Lummer-Brodhun screen.

Dr. A. S. McAllister:—The authors have made some instructive comparisons of the relative merits of the constant-length, constant-intensity and constant-radius types of distribution photometers. They have done well in calling attention to the advantage of photometering lamps with reflectors at a certain constant radius and expressing the measurements as "apparent candle-power" at the distance chosen. The fact of the matter is that the candle-power measured at any other than a constant radius with certain types of reflectors, may mean little or nothing; with the true parabolic reflector arrangement the apparent candle-power varies directly with the square of the radius, so that the unmodified term "candle-power" used with such an equipment is certainly untrustworthy, if not misleading.

In addition to giving reliable candle-power data that can be properly interpreted, the constant-radius photometer gives an absolutely accurate indication of the mean spherical candle-power. The mean spherical value for the "apparent candle-power" obtained at any constant radius drawn around any point whatsoever—the only requirement being that the spherical surface described completely surrounds the lighting source—is the abso-

lutely accurate mean spherical candle-power of the source, without regard to its size or the regularity in the space distribution of its apparent candle-power. These facts are discussed at length in my paper on "The Law of Conservation as Applied to Illumination Calculations," to be presented at this convention.

Mr. G. H. Stickney (in reply):—Answering Mr. Millar's inquiry, I wish to say that we did have considerable trouble in first calibrating the twin mirror photometer to eliminate the variations due to the angle at which the light from the test lamp was received at the photometer disk. The solution, of course, was the provision of a sufficiently good diffusing surface on the disk itself. After considerable experimentation, this was eliminated by the use of the Lummer-Brodhun screen. Another difficulty encountered was the bending of the frames supporting the mirrors, which were very large and heavy. While the construction was made very heavy in the original design, we found it necessary to introduce additional bracing to stiffen the supporting arms.

We have never made any tests which show the intensity for all angles of elevation at the same instant. This would unquestionably complicate the construction considerably and the principal demand we have had has been for the mean illumination over a fairly long period. On this account, we have relied rather upon a large number of readings, taken in various series so as to eliminate, as far as possible, any instantaneous effect or condition. We have endeavored to set forth in the paper our realization that the average intensity does not quite represent the lighting value of sources which vary from instant to instant. Unquestionably this value would be different for a lamp used singly from that of lamps used in groups. Under present conditions the average value is undoubtedly the most useful. This can often be supplemented by readings taken to show the character of the variation from instant to instant.

Attention has been called in the discussion to the fact that the record sheets call for but ten readings at a point. This is intentional. It is the practise to make a large number of series of readings around the lamp, rather than to take all the readings at one angle of elevation in one continuous series. These various series are averaged point by point and thus the effect of the

time factor on the shape of the photometric curve is practically eliminated.

Mr. Little has called attention to the light reflected from the edge of the mirror, as indicated in the lantern slide. In explanation of this, I would say that the effect is very much exaggerated in the slide. As a matter of fact, a dull black wooden strip extends around the edge of the mirrors. This strip is scarcely visible when actually looking at the mirrors from the photometer screen. Errors from this source have been investigated, however, and tests have shown that no commensurable light is received on the photometer when a small screen is interposed between the mirror and the photometer to cut out the image of the light source itself.

The point has also been raised regarding the practise of eliminating, readings when the unit is not operating under rated conditions, that is, with regard to current and voltage. This question is one that has been thoroughly studied and discussed and we have always concluded that it was preferable to eliminate such readings whenever we were trying to determine the average performance of a type of lamps; characteristics peculiar to the individual lamps tested have always been eliminated. In this way, we have obtained much more representative and consistent readings. It should be understood that mere variation in candle-power is not considered cause for eliminating readings.

We have never had any serious difficulty with the use of the sector disk with alternating current arc lamps. Occasionally we have operated the sector at speeds which approached synchronism. This, however, is immediately evident to the observer, and, since we were using a direct current motor, it was an easy matter to vary the speed to overcome any stroboscopic effect. I would, however, anticipate much more difficulty if the flicker photometer were used.

In answer to the question as to why it is more important to screen a powerful light source than a small one, I believe this will be evident when it is considered that, with the sector disk, the intensity on the photometer screen is maintained at a low value, even for a powerful source.

We have never made any tests to show the change in coeffi-

cient of reflection of mirrors with change in the quality of light. We have, in a few extreme cases, where this point was in question, checked our horizontal measurements with other readings without mirrors, and satisfied ourselves that there was no commensurable error introduced by the mirror. Of course, this would be a much greater source of error if two more mirrors were used in series.

Mr. Millar has spoken of the use of automatic recorders. Undoubtedly this would be of great assistance under conditions to which they are suited as, for example, certain physical laboratories. Under the conditions that have existed in Schenectady and Lynn laboratories, where many different illuminants are tested one right after the other and where it is frequently necessary to break in new observers, we have found it preferable to keep the apparatus as simple as possible to eliminate errors. I am still convinced that the automatic recorder would be a questionable economy under these particular conditions. As our method requires us to have a number of observers so that they may be interchanged, no hardship is introduced by having the values written down as observed.

Referring to Mr. Millar's suggestion of the advantage of using an integrating photometer, particularly for the testing of electrodes, etc., I may say that, while a diffusing-box photometer has been used in the Lynn laboratory, it has been our practise to get these comparative results by means of readings at fixed angles, the characteristic having been already determined.

I see no reason why Dr. Ives' suggestion regarding the determination of the characteristic shape of the photometric curve by comparing light at various angles with the mean intensity or with the intensity at some particular direction, could not be carried out. It would, however, complicate the construction of the present apparatus used at Schenectady. While I have heard of a similar suggestion before, I have never taken occasion to try it out and so I am not prepared to say how satisfactory it would be.

Mr. Hussey has called attention to the single-mirror photometer, as used at Lynn. We have made very careful checks with Mr. Hussey's photometers, and the results have always been exceedingly satisfactory. Mr. Rose, who has worked with both

the single-mirror and twin-mirror photometers, has a very decided preference for the twin-mirror instrument. In comparing the Lummer-Brodhun and Bunsen types of screen, he chose the former for the twin-mirror photometer despite the fact that he had always used the Bunsen up to that time for the single-mirror photometer.

PHOTOMETRY AT VERY LOW INTENSITIES.[1]

BY LOUIS BELL.

For several years past the author has had occasion to make many photometric measurements of street lights, both gas and electric; and while the more powerful lights of either sort at moderate distances have presented no particular difficulties, the necessity of working with a very feeble illumination on the photometer screen has been only too common. The difficulties encountered when attempting photometry under illuminations of less than 1 meter-candle led to a study of photometric conditions in very faint light, of which the present paper is the outcome.

It is well known that for moderate illumination, Fechner's law holds with a good deal of precision, so that about the same percentage of difference in illumination can be perceived over a very wide range of intensity, this percentage being in the normal eye somewhat less than one per cent. Any photometrist realizes the closeness with which he can discriminate shades of illumination on his photometer disk, and that in comparing lights of the same color the maximum departure from the mean of a set of readings is usually decidedly less than 1 per cent., when the intensities compared are of the order of 20 or 30 meter-candles. When, however, one deals with illuminations of one tenth of this amount or below, the shade perception appears to be seriously impaired; so that there is a tendency for photometric readings to vary over a considerably greater range than before. This tendency has been especially noted when the illumination has dropped below 1 lux and is particularly exaggerated under ordinary circumstances in the region below say 0.25 lux, where the normal cone vision of the eye has almost completely disappeared and one is left dependent on rod vision alone. In the course of many observations at these extremely low illuminations the writer has observed, however, very erratic variations

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society Chicago, September 25, 26, 27 and 28, 1911.

in the precision of setting. Of course a series of photometric balances gave immediate data for evaluating Fechner's fraction, and in so doing the fact became conspicuous that the values thus ascertained for approximately the same illumination were subject to very wide variations. This led to a more careful study of the relations of Fechner's fraction to the illumination in the region below 1 lux, and it soon appeared that with proper care in keeping light out of the eye Fechner's fraction became less erratic in its values and settled steadily to a smaller percentage. A very little dazzling from stray light will spoil one's shade-perception for faint differences in intensity, as every observer has noted; but it has seldom been fully realized to what extent conditions are improved by even a moderate degree of adaptation to dim light. There have been a good many investigations of adaptation, most of them unhappily buried where the average photometrist does not readily get at them.

Fig. 1, from the researches of Charpentier, shows in a very striking manner the increase in sensibility as the eye is adapted for lower and lower illumination. In this figure the abscissae indicate the relative illumination for which the eye was adapted, beginning with moderate daylight illumination, the data unfortunately not being in absolute measure. The time allowed for adaptation at each stage was comparatively short—about three minutes—and for each stage of adaptation the minimum perceptible light in the field was determined. The ratio in sensibility, under these conditions of adaptation, as between diffused daylight on a cloudy day and complete darkness was 1:225, as shown on the curve of fig. 1. In other words even this brief period of dark-adaptation gave the eye two hundred and twenty-five times its former sensitiveness to faint light. One can readily realize, therefore, the increased precision in setting a photometer, which is likely to follow the exclusion of extraneous light, when dim fields are under consideration, and the disastrous results of even an apparently trivial amount of glare reaching the eye. How far this difference would affect the value of Fechner's fraction remains to be seen, but it is clear that the effect would be large. When one considers beyond

this the result of more complete adaptation gained by longer periods in darkness, the results are much more striking.

Fig. 2, also from Charpentier, shows the rise in sensibility in dark adaptation extending up to the comparatively brief period of eleven minutes. The rise in sensibility is slow at first and then becomes more rapid, reaching at the end of eleven minutes about

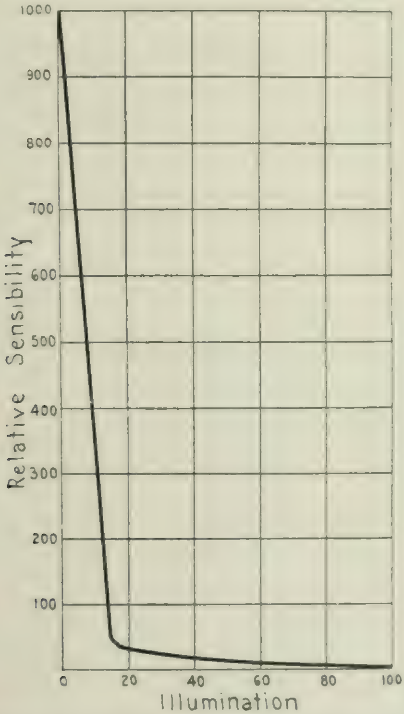


Fig. 1.—Sensitiveness of the eye to decreasing low intensities of illumination

fifty times the initial value. It is clear therefore that with prolonged adaptation there is an immense gain over even the maximum shown in fig. 1. At this point, eleven minutes, Charpentier stopped; but a later research by Piper[1] carries the gain in sensibility with the time of adaptation up to above an hour, with most astounding results.

Fig. 3 shows Piper's curve for the two of his eight subjects who

[1] *Ztschr. f. Psychol. u. Physiol. d. Sinnesorg.* vol. 31, p. 161.

showed the greatest sensibility. It will be observed that at about ten minutes the sensibility begins to rise very rapidly, as shown in Charpentier's curve, fig. 2; but with further increase in the time of adaptation it keeps on rising at a prodigious rate until in a little less than an hour it reaches a nearly asymptotic value, in this case some eight thousand times as great as the initial figure. All the cases examined by Piper show the same general phenomena, but in a varying degree, the least increase being to some fourteen hundred times the initial value. Most of the increase occurred in the first forty-five minutes and the rapid increase began at about ten minutes. Prolonged adaptation therefore puts the eye into a condition in which it can dis-

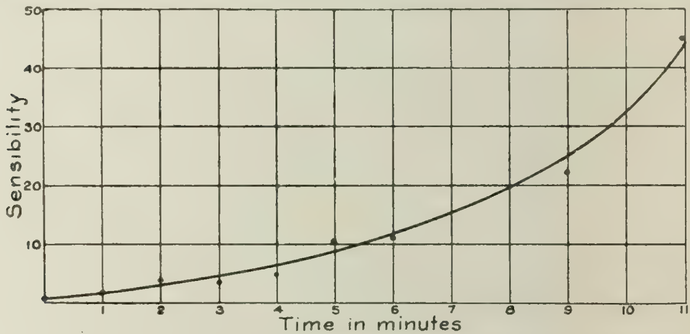


Fig. 2.—Increase in sensibility of the eye to illumination with time of adaptation.

criminate faint illuminations in a way that is altogether surprising to those who have customarily worked with fields of ordinary intensity. This fact has, of course, been well known to astronomers since the days of Sir William Herschel, who habitually kept his eyes bandaged for some little time before beginning delicate observations of nebulae and faint stars.

Obviously any intrusive light of even moderate intensity will very rapidly spoil this extreme dark adaptation. As the author has many times observed in field photometry, it is even necessary to be very cautious in varying the intensity of the comparison field in order not to dazzle the eye after it has remained a few minutes in darkness. Very little is known regarding the performance of the eye under the conditions of extreme adaptation here indicated. The time required is far too long and the gain is far too readily lost to enable one to take practical ad-

vantage of extreme conditions. But the results which can be reached even by dark adaptation for ten minutes or so, with careful avoidance of unnecessary light in balancing the fields, lead to some rather extraordinary conclusions.

It may here be mentioned that the very rapid rise in adaptation after eight or ten minutes corresponds to the active re-

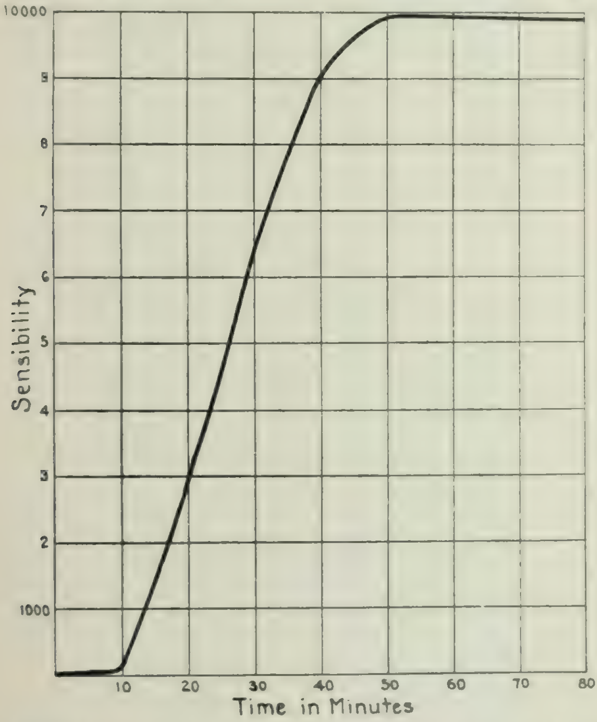


Fig. 3. Increase in sensibility of the eye to illumination with prolonged adaptation

generation period of the visual purple as nearly as can be ascertained by experiments on animals. With dogs for instance, the regeneration noticeably sets in after about seven minutes and reaches an apparently full value in from thirty-three to thirty-eight minutes[2]. The loss of visual purple in exposure to light is, however, very much more rapid than its gain in darkness.

To test the effect of adaptation on the value of Fechner's fraction and hence on the precision of photometric measurements at low intensities, the author carried out a considerable series of

[2] Nagel, *Handbuch d. Physiol. des Menschen*, vol . , p. [illegible]

experiments both with a photometer in the field and on the ordinary photometer bar, in each case using an ordinary Lummer-Brodhun prism for equality of brightness. The results of a large number of the series of observations of this kind are shown in fig. 4, the various points obtained being plotted thereon. The circles and crosses in the figure represent observations, partly in the field and partly in the laboratory, by two different observers; while the black dots are values taken in the laboratory with especial care with respect to maintaining a fair degree of adaptation. In these observations the illumination, reduced to meter-candles, is that determined from the mean of ten settings. $\frac{dI}{I}$ is the complete percentage range of settings including all the observations from which the corresponding value of I is derived. The values of illumination range from about 5 meter-candles down to a few hundredths of a meter-candle. The fraction $\frac{dI}{I}$ is of course proportional to Fechner's fraction, representing as it does the practically certain range of discrimination between the photometer fields. It is numerically larger than the ordinary values given for Fechner's fraction merely because these latter values are not stated in terms of the whole variation in settings. It will be seen that these observations are in the extreme corner of the ordinary graphic representation of Fechner's fraction, close to the origin, and all the intensities are considerably below those usual in such experiments. Curve *a*, fig. 4, is plotted from the observations of König, in so far as they lie within this region, and shows how completely even moderate conditions of adaptation change the ordinary conception of the increase of Fechner's fraction at low intensities. Curve *b* was drawn through the observations before the points representing the most complete adaptation were added. It shows only a slight increase in Fechner's fraction until one gets down fairly into the region of rod vision and then the values of $\frac{dI}{I}$ go wild, varying from less than five per cent. to perhaps 70 per cent. for the same illumination.

At a slightly greater illumination, say half a meter-candle,

there is still considerable variation in Fechner's fraction, but of a far less conspicuous character. The region of great variability is not entered until one reaches the point at which cone vision practically ceases and is replaced by nearly pure rod vision. This point appears to be at or a little below 0.2 meter-candle. At this point in the diagram begin the large variations of Fechner's fraction, corresponding to the state of dark adaptation of the eye. This in turn corresponds to the variations in the amount of visual purple which affects, at least for anything except extreme adaptation, the rods only.

The point of the full establishment of rod vision is therefore

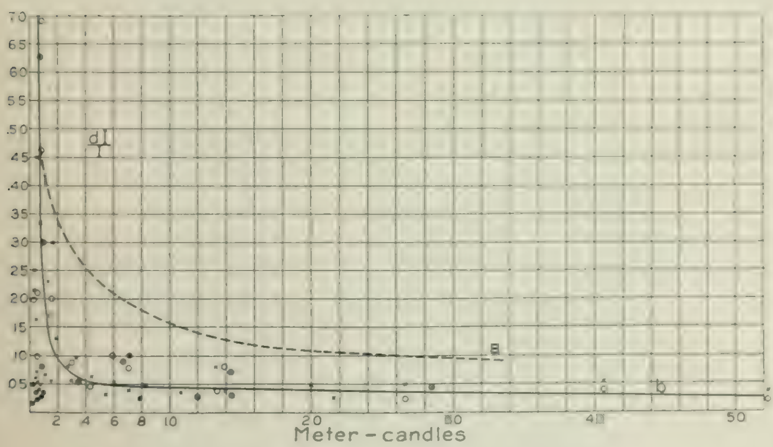


Fig. 4.—Effect of adaptation of the eye on the precision of photometric measurements at low intensities of illumination.

set by these observations practically at the same point established by Dow[3] by the radically different process of determining the point at which the failure of cone vision causes the color sense to vanish. This point may fairly be considered to represent the dividing line between cone and rod vision for a moderate degree of dark adaptation. It will be noticed in looking at fig. 4 that down to the neighborhood of this point Fechner's fraction remains quite uniform and save for the variations due to varying adaptation at about the same value found for 5 meter-candles or more.

[3] *Proc. Phys. Soc. Lond.* vol 20, p. 215.

What now is the effect of a greater degree of dark adaptation? The dotted points added to fig. 4 in the corner near the origin answer this question, at least in part. These points are established by the comparison of very faint lights on the photometer bar. The room was thoroughly darkened, the lights carefully screened and the utmost care was taken to avoid exposure of the working eye to light. The right eye was used for the comparisons and the left for reading the scale. Under these circumstances $\frac{dI}{I}$ even for illuminations down to a one or two hundredths of a meter-candle remained sensibly the same as the value found for ordinary moderate intensities on the screen. Even here the dark adaptation was far from complete, having extended over periods not much exceeding one quarter of an hour.

It therefore appears that with fairly thorough dark adaptation the value of Fechner's fraction remains sensibly constant from its values at ordinary illuminations down certainly to a few hundredths of a meter-candle. The rapid increase of Fechner's fraction which has often been noted at illuminations near and below 1 meter-candle seems to be due wholly to imperfect dark adaptation. How much further down toward the threshold of vision the fraction holds to its nearly uniform value can be told only by pushing dark adaptation as nearly to the limit as is practicable. Without great care in adaptation the values obtained vary enormously as one enters the region of rod vision. With it, the curve representing Fechner's fraction becomes practically a straight line parallel to the horizontal axis.

Theoretically this point is of considerable interest as showing the precision of the psycho-physical law; practically it is of importance as showing the imperative necessity of care and good dark-adaptation whenever photometry at very low intensity is undertaken. The phenomena observed in making photometric balances near the limit of visibility are very curious, and they bear out in an interesting way the observations of Burch, recorded in the *Philosophical Transactions*, a few years ago.

When first attempting to make the photometric balance the conditions seemed quite hopeless, the field being a faint blur of light

confused by a shadowy and irregular flicker. As adaptation proceeded the field grew brighter and then suddenly the central spot would flash out, showing the contrast one way or the other, which permitted readjustment. Finally, the blur cleared away and a set of consistent settings could be obtained quite comparable in precision with those reached at much higher intensities. No attempt was made to get readings until this comparatively stable state was reached, when settings could be made in the ordinary manner and with a facility that at the beginning of adaptation seemed entirely out of the question.

No quantitative acuity observations were attempted at this point, but the conditions of vision were such as to show very much greater acuity than with the unadapted eye. This condition tends to bear out a statement of Uhthoff quoted by König,[4] that eyes in which visual acuteness was great showed most quickly the dazzling effect of too much light; while eyes feeble in acuteness endured it much better, thus indicating a close inter-relation between acuity and the conditions of adaptation.

The reference to Burch's researches introduces another point regarding vision in dim light which deserves further study. Burch found that with very prolonged adaptation, extending over one or several hours, the color sense returned so that color perception could be carried down to the very threshold of vision. The author has not had opportunity to follow up in that direction the investigations here recorded, but an observation made three years ago throws an interesting sidelight on the matter. The author at that time was examining the spectrum of the aurora by means of a pocket spectroscope. The degree of illumination, although the aurora was fairly bright as auroras go, was, of course, very low, certainly well within the region ordinarily relegated to rod vision. Yet the spectrum presented the appearance shown in fig. 5. Four of the well known auroral lines were plainly visible and the two in the blue end of the spectrum, while very faint, were unmistakably blue and not greenish like the others. The place of observation was on a mountain top without trace of disturbing light of any kind and the blue lines came out only after prolonged observation cor-

[4] *Nature* vol. 31, p. 476.

responding to an adaptation period of probably at least half an hour. Other spectroscopic observations of very faint sources have given the writer similar evidence of unexpected color. These intimations of returning color vision with prolonged adaptation are pertinent in connection with the observations of Dr. Edridge Green[5] in which he found in the retina of monkeys kept in the dark for forty-eight hours a migration or development

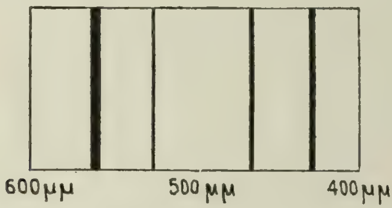


Fig. 5.—Auroral spectrum observed September 4, 1908.

of the visual purple fairly within the fovea where it was found between the cones.

To recapitulate; with the imperfectly adapted eye exposed to casual light and never given a fair opportunity for regeneration of the visual purple, the value of Fechner's fraction rapidly rises below 1 meter-candle and both shade-perception and acuity are uncertain. With illuminations near and below 0.2 meter-candle the value of Fechner's fraction obtained becomes practically a function of adaptation and has no significant average value. With reasonably good dark adaptation Fechner's fraction becomes substantially a constant, down to the very lowest illuminations observed. Acuity shows great increase by prolonged dark-adaptation and there are found at least signs of returning color vision.

DISCUSSION.

Dr. P. W. Cobb:—This paper emphasizes especially two points that I think are very interesting, first in regard to the change in the functions of the eye under different intensities of illumination and second the time required under any particular intensity for the functions of the eye to reach a constant value.

[5] *Berl. klin. Wchschr.*, 1909.

Perhaps the most striking work that has ever been done on this question is the work of Piper, which Dr. Bell has quoted here and the results of which are shown graphically in figure 3. The ordinate is the sensibility of the eye measured by the reciprocal of illumination required on the surface, (a square, whose side represented 18 degrees in the visual field) to make that surface just visible and it was found that in two of the eight subjects so used, that the sensibility of the eye increased, as Dr. Bell says, some eight thousand times in the course of an hour spent in darkness. The increase was slow for ten minutes, then more rapid, and the maximum was reached in 45 minutes or an hour. The smallest increase noted in any of those eight subjects was about 1,500-fold. These, it must be understood, are figures which relate to the least perceptible stimulus that will be perceived as light at all. It is reasonable to suppose that other functions of the eye would undergo a change in a somewhat similar way during a certain time immediately after the eye has been removed from a high illumination to a low one.

It has been shown, whenever the functions of the eye have been investigated exhaustively under as nearly identical conditions as possible and over an extremely wide range of illuminations, that when a very low illumination is reached, the mathematical relation between illumination and the sensibility of the eye is different from the one found to hold at higher illuminations. In the case of Fechner's fraction that same difference has been found. Over a wide range, at what we call moderate intensities Fechner's fraction for white light is practically a constant. Below this range the fraction increases with decrease of illumination. The series of observations of König and Brodhun is the most complete set of values for Fechner's fraction that we have, and Dr. Bell has plotted the results obtained by König.

Then arises in the case of very low intensities the question of the difference in Fechner's fraction which will result if time is allowed for the complete adaptation of the eye to take place, for the eye to assume its maximum possibility for those intensities.

In the work of König and Brodhun, I found upon reference to the original paper, that the observer was kept in the dark by

means of a curtain of black material enclosing a small space in which he sat. The eye-piece of the instrument was put through a hole in this curtain. It was stated that the observer was kept as far as possible in darkness during the course of the observations, but it is not stated how long he remained there before the observations were begun.

Dr. Bell's results are quite startling. By waiting about fifteen minutes in darkness he finds that the photometric sensibility of the eye is increased about ten-fold, that is, Fechner's fraction decreases to about one-tenth of its initial value. He also gives an additional hint on the eighth and ninth pages of the paper as to how the photometrist may judge a favorable time for making a setting: "When first attempting to make the photometric balance the conditions seemed quite hopeless, the field being a faint blur of light confused by a shadowy and irregular flicker. As adaptation proceeded the field grew brighter and then suddenly the central spot would flash out." This phenomenon can be readily observed by attempting to read very coarse print in a light at first too feeble to reveal the letters. After a short interval, as adaptation proceeds, the letters will be seen to flash into visibility at times for an instant and disappear, being quite distinct at one moment and totally obscure the next.

One of the things which at first sight would seem to stand out against the theory that the rods in our retina and the cones act independently is the reappearance of colors with adaptation at low intensities. According to the duality theory, the cones are capable of transmitting to consciousness either color sensations or colorless (simple brightness) sensations. They do not increase greatly in sensibility at low intensities of illumination. The rods, on the other hand, are capable only of simple brightness sensation, not of color sensation at all, but increase tremendously in sensibility after an interval at low illuminations. Arguing from this point, the increased sensibility of the eye resulting from dark-adaptation should be an increase in brightness sensibility alone, and not of color sensibility.

Burch found however that after two hours adaptation to complete darkness he was able to see color at the lowest intensities sufficient to cause any sensation, which could not be the

case if the rods acted alone and were incapable of furnishing color sensations.

Dr. Bell reports near the close of his paper that he was able to see color in the spectrum of the aurora after a half hour's adaptation to darkness, when the illumination was extremely feeble,—probably well within the limits ordinarily assigned to rod-vision. This observation tends to the same conclusion as that of Burch, namely, that the duality theory, like the other theories brought forward to explain light and color vision falls short of completeness.

Prof. S. W. Ashe:—Dr. Bell's paper calls attention to one of the most difficult problems in photometry of the present day, that is the photometry of lights of low intensities. Some of us may feel that in the flicker photometer at ordinary intensities, there is a means of fairly accurately measuring light differing in color. Dr. Bell's paper gives considerable valuable information on the photometry of lights of low intensities similar in color. At present, however, the problem of photometering light differing in color at very low intensities, is yet to be solved. Probably there are three physiological factors which must be considered, namely adaptation, glare, and fatigue. Dr. Bell deals quite fully with the importance of adaptation and also with the necessity of eliminating all glare. I do not think, however, that Dr. Bell had laid sufficient stress on the matter of fatigue, which must be carefully watched for, and the duration of measurements regulated accordingly, if one expects to get accurate results. That is, there is a certain definite period over which one can work. Beyond that one must desist because the element of fatigue impairs the results obtained. Fatigue is especially noticeable where one is working with light of low intensity.

There is one other point to which I wish to direct attention: that is the curve in fig. 4. I don't think that the accuracy there is very great. Down near the abscissae the variation does not show, but I think the variation in the reading calculation would be forty or fifty per cent.

Dr. H. E. Ives:—I have been very much interested in this paper of Dr. Bell's, because recently I have been doing some

work along a slightly different line, which however seems to offer many similarities. Perhaps they are very fundamental similarities. I have been working during the past two years on the general question of the photometry of lights of different colors. Now, in order to unravel some of the rather obscure phenomena of the flicker photometer, I have lately been studying the question of critical frequency. You all know that a sector disk rotating fast enough will no longer appear to flicker. The speed at which flicker disappears is called the critical frequency. If the logarithm of the illumination is plotted against the critical frequency a straight line is obtained. The phenomenon in fact follows Fechner's law, $\frac{dI}{I}$, corresponding to a constant speed difference. Above an illumination of about 0.25 meter-candle the straight line for white light has one slope. At this illumination the line takes a sharp turn and continues at a different angle, that is, the Fechner fraction changes in value.

I have been studying these straight lines for the various spectrum colors, with rather interesting results. For the different colors in the spectrum I find that straight lines of different inclinations are obtained. Red light plots as a line at one angle, blue another. If the illumination is decreased, the line for red goes straight on down, but the line for the blue, when it reaches a certain point, abruptly turns and continues in a horizontal direction. It is impossible to measure blue light by means of critical frequency below this point. Fechners fraction becomes infinite. Now the thing that interests me is this connection which Dr. Bell has suggested, between the presence of the sensation of color, and the value of Fechner's fraction. This point where the blue curve gives a sharp turn, is also the point where the color no longer is blue, but is gray, where, according to one view, the change takes place from cone to vision I have not so far tried the effect of adaptation. It may be that with a dark adapted eye this blue curve, instead of striking off horizontally may go straight on down, just as the red curve does At any rate, it seems to me very suggestive, and I am exceedingly glad that the point has been brought out, that perhaps

we have here a criterion as to when settings at low intensity should be made. Perhaps when we can see color, we are ready to make photometric measurements. I think we all remember the story in history that when Dr. Bell's home town was being attacked by the Red Coats, the patriots were ordered not to fire until they could see the color of the enemy's eyes. Perhaps the future text book on photometry will contain the admonition "Don't make you settings until you can see the color of the field!"

Dr. E. P. Hyde:—Dr. Cobb, as I understood him, could not find a statement in Dr. Bell's paper as to the time of adaptation. On the eighth page of the paper at the end of the first paragraph Dr. Bell says, "Even here the dark adaptation was far from complete, having extended over periods not much exceeding one quarter of an hour."

Prof. Ashe comments on the accuracy of Dr. Bell's curve. I do not think from reading Dr. Bell's paper that he means to convey the impression that the curve is extremely accurate. He rather wants to bring out the point that when some attempt is made at adaptation, when some time is given for adaptation, the ordinates are considerably reduced. Whether or not Dr. Bell's curve rises rapidly near the axis of ordinates doesn't seem to be of any great significance. As the curve rises the sensibility drops off, because the adaptation hasn't been carried to very low values. The black dots show that if one does take the pains to get very excellent adaptation if one does give sufficient time for adaptation to very low illuminations, then the ordinate is considerably reduced even at these very low illuminations.

There are one or two things that I should like to add in the way of discussion. One point which is suggested by Dr. Bell's paper but which Dr. Bell does not attempt to cover, is the question of the adaptation of the eye in ordinary photometric observations. Dr. Bell is concerned with the adaptation of the eye to photometric observations when the intensity of illumination is very low, and the conclusion is that the adaptation should be for a long period and to a very low illumination. Now, a very practical question which has arisen in my own work, and which I am sure it has come into the experience of others, is that of

the proper adaptation in ordinary photometric work. If one is working with an intensity of illumination of fifteen or thirty meter-candles, should his eye be adapted as nearly as possible to perfect darkness, or should it be adapted to an illumination of the same magnitude as that at which the settings are to be made? To put it even more explicitly, is it a good thing to cover the light sources and make the walls of the room perfectly black when one is going to make photometric observations in a photometer where the illumination is thirty meter-candles? It would seem to me, that without specific knowledge to the contrary, it would be better to have the general illumination of the same order of magnitude as that of the photometer field where settings are to be made, rather than to have the eye adapted to a very low intensity of illumination. I am inclined to think that as we study this question of the relation between the intensity of illumination at which settings are to be made and the intensity of illumination to which the eye is adapted we shall find that the sensibility of the eye at any intensity of illumination is greatest when the eye has been adapted to an illumination of the same intensity. Dr. Bell's paper suggests a very interesting research for someone in a study of the variation in the Fechner fraction for ordinary intensities of illumination when the eye is successively adapted to various intensities of illumination extending over a wide range.

THE DISTRIBUTION OF LUMINOSITY IN NATURE.[1]

BY HERBERT E. IVES AND M. LUCKIESH.

There is little dispute that in natural daylight illumination. out of doors, one finds some of the most pleasing distributions of light. There can also be no question that the human eye has by adaptation become most accustomed to these distributions, and finds in them its most healthful activity. It is still, however, an open question whether under the practise of continuing human activities into the night—a practise comparatively new in terms of the history of the race—the same character of illumination conditions as in daylight are best. Or ought artificial light indeed be markedly different in composition and distribution from natural light? Only experience and refined physiological methods of testing can settle this question. However, the generally admitted fitness of daylight conditions to the eye has made the natural light of the sun and sky a rather frequent standard to which artificial systems are compared. Thus a purely indirect system finds adherents because it simulates the extended bright sky; localized lighting gives the directed shadows of sunlight, and combinations of the two imitate more or less closely the partly directed and partly diffused light of day.

Now, whatever one's opinion, or the ultimate weight of evidence as to the advisability of imitating daylight at night, it is nevertheless of interest and importance to know with some definiteness what the pleasant daylight conditions actually are. That done, it will be possible to imitate them artificially with probably greater exactness than do any present installations which frankly claim similarity to daylight distribution as one of their advantages.

A complete analysis of daylight illumination would, of course, be very elaborate. In it the questions of intensity of illumination, color of illumination, direction, diffusion, and other factors must enter. The present study is confined to the distri-

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society Chicago, September 25, 26, 27 and 28, 1911

bution of surface brightness in certain cases of out-of-door illumination. Up to the present little more has been done than to develop the method. Some results are, however, presented and offer several points of interest.

It was thought proper to study surface brightness rather than intensity of illumination because the various surfaces out of doors are of different reflecting power from those of interiors. A close reproduction of the direction, intensity and diffusion of daylight would not necessarily give a similar result in a room, while a distribution of surface brightness could be copied by proper choice of wall coverings and furniture. In other words the data here obtained would be suitable for an illuminating engineer who had the privilege of specifying the wall paper as well as the lighting units.

A photographic method of photometry has been used for the obvious reason that the number of readings which would be required, and the constantly varying intensity of illumination, practically prohibit the use of an illuminometer. The details of the method follow:

In order to use the photographic plate in photometry its sensibility to lights of different colors must be like that of the eye. Ordinarily this is not so. All photographic plates have their maximum sensitiveness for blue or violet light; orthochromatic and isochromatic plates are also sensitive to green, yellow and red, to varying degrees, but never so sensitive to those colors as to blue.

The first step in the investigation was then the preparation of an absorbing screen or "ray filter" which would make photographic action for different colors proportional to visual brightness. This means that the sensitiveness of the plate to the spectrum must be as the luminosity curve of the normal eye. Such a screen was made by experiment, using various dyes in gelatin films on glass. First a set of test patches were exposed, for a given fixed time, the illumination being different for each. This negative was developed for a certain number of minutes in developer of standard composition and temperature. Each patch on the plate then corresponded to a known illumination. Next spectrograms of a white sunlit surface were taken using the same time of exposure and procedure in development. Meas-

urements of density on a photometer made possible a plot of the relative illumination value of each color as rendered by the plate. After considerable experiment a screen was produced, whose constituents were rhodamine, tartrazine, naphthol green and aesculin, which fulfilled the desired conditions. In fig. 1 are plotted the luminosity curve of the spectrum for sunlight[1] (full line), and (circles) the rendering of the spectrum by the plates used (Cramer spectrum) with the special screen. The approximation is sufficiently close for the present purpose.

A photograph made through this screen can be measured for density at any point, and the distribution of brightness in the

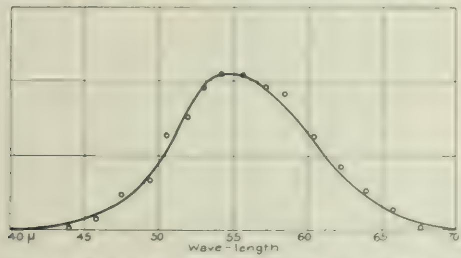


Fig. 1. Luminosity curve of white light spectrum (full line). Rendering of this curve by plates and ray filter used (circles).

field of view be represented by a set of plots or by a solid figure. The preparation of such a set of plots or solid figure did not, for the present, seem as feasible or as useful as would some kind of average; in particular, an average of the vertical distribution of brightness through the angle of vision of the eye. To obtain such an average it was necessary, because of the narrow angle of available photographic lenses, first of all to make a number of exposures—six—in order to photograph the complete field between 70° below the horizontal and 50° above, with sufficient overlapping for safety. Next some arrangement was necessary in order to perform the averaging operation automatically. For this purpose a cylinder of glass was placed before the photographic lens, or, what was practically equivalent, a bottle filled with a solution of chloral hydrate in glycerin. This strong cylindrical lens had the effect of throwing everything badly out of focus horizontally, leaving the vertical definition practically unaffected.

[1] H. E. Ives. *Trans. I. E. S.*, Oct., 1910

On each plate two exposures were made, one without the averaging device; the other with it. The two exposures were kept separate by the use of two special diaphragms in front of the plate. Fig. 2 shows the camera as arranged for tilting to various angles and for holding the bottle. To the right are shown the two diaphragms, one with a narrow slot for the bottle exposure, one with the complementary opening for the unaveraged

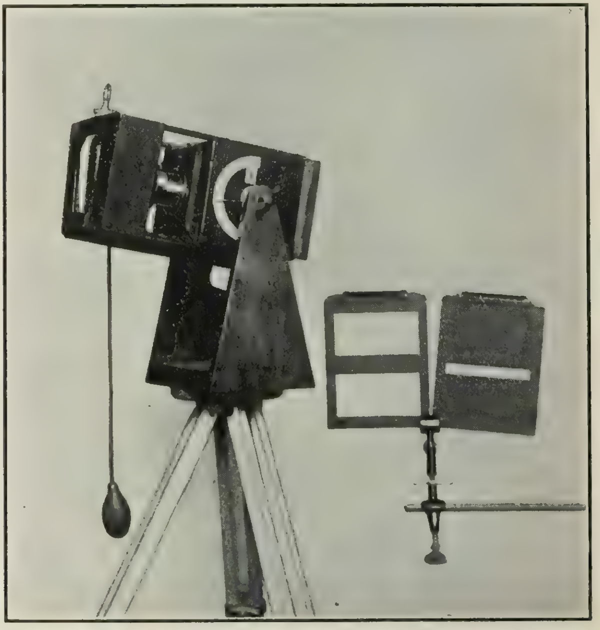


Fig. 2.—Special camera of photographing vertical distribution of brightness.

picture. The opaque portion of the latter diaphragm is made extra wide so as to leave an unexposed space against which the densities of the averaged strip may be measured. The mode of action will be readily comprehended after examination of the photographs so made (figs. 3 to 9).[2] A panoramic camera arranged to rotate around a horizontal axis would obviously have been preferable, but one was not available.

[2] In inspecting the illustrations it must be remembered that the range of gradation of the photographic plate is much less than the range of intensities in nature, and that there is a further loss in the printing process. Consequently the prints do not show the extremes of light and shade which the measuring process show to have existed in the original views.

RESULTS.

A number of photographs of out-door scenes are shown in figs. 3 to 9, and in figs. 3a to 9a are given plots of the average distribution of brightness in the vertical plane. In taking these pictures an effort was made to secure typical out-of-door views of a well marked pleasant or unpleasant character as judged by the authors at the time. What constitutes pleasant and unpleasant is of course to a large degree a matter of personal opinion, and it is only a personal judgment that is here presented. The aim was, however, to select views of such well marked character that there was little room for difference of opinion. The pictures include two pleasant landscapes, two views of the same open landscape under different conditions (pleasant and unpleasant), a shady place in a park (pleasant), a city street (indifferent), and two street views of markedly unpleasant but yet instructive character. In the search for these views a great deal was learned—almost more than from the pictures themselves. The most striking fact—impressed upon the authors after many miles of tramping in parks and suburbs—is that nature is far from uniformly pleasant to gaze upon. In fact it has been borne in upon us that the chief difference between good and bad in a landscape consists in one thing, namely, the presence or absence of long shadows. The same scene, observed at midday with the sun overhead and then pronounced glaring and ugly, will in early morning or late afternoon be bearable or even charming. Similarly on over-cast days, without the directed shadows of sunlight, an attractive landscape becomes dull and characterless. Compared to the sky as a standard the average brightness of the foreground is at one extreme with midday sun, at the other with the overcast sky. Neither pleases, and from the authors observations, as illustrated in the figures which follow, it seems improbable that a mere mean of the two conditions would introduce the attractive characteristics given by the variety of light and shade under oblique sunlight.

This observation has an immediate bearing on artificial illumination, for in nearly every case our artificial light whether direct or indirect, comes from overhead, the very condition under which nature is least pleasing. Lighting by table lamps or wall brackets—in either case out of the observer's line of vision—

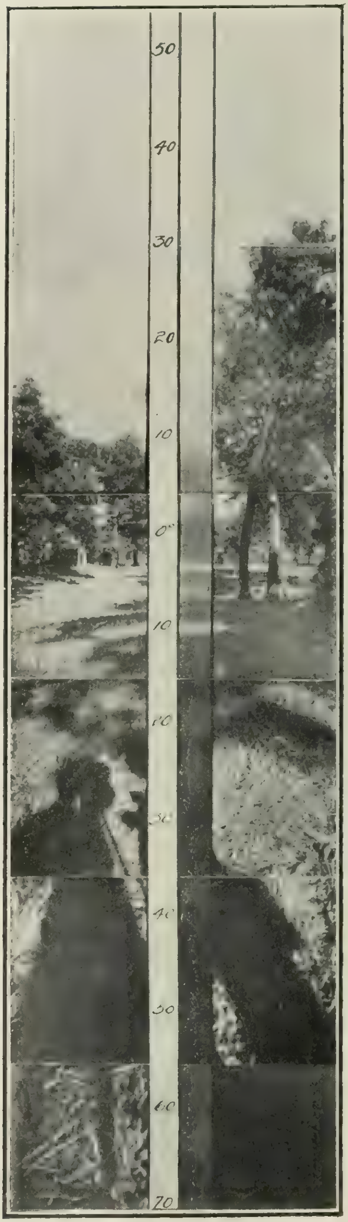


Fig. 3.—View near Rocky River, Cleveland.

Fig. 4.—View at Rocky River, Cleveland.

would therefore appear to conform more nearly to pleasant natural conditions. This matter is dwelt upon because, while one of the most important factors, it might yet escape the photographic averaging method.

A brief description of the several photographs will assist in drawing conclusions.

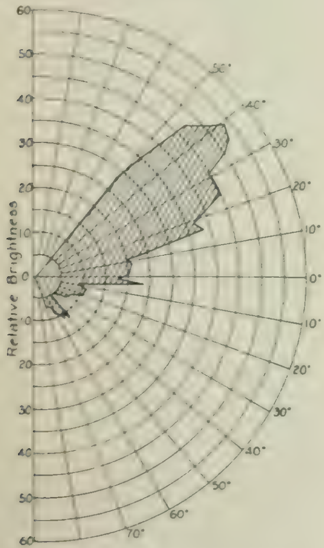


Fig. 3a.—Vertical distribution of brightness for fig. 3.

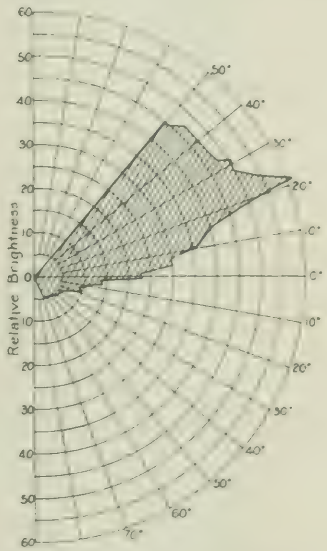


Fig. 4a.—Vertical distribution of brightness for fig. 4.

Fig. 3 is a view at Rocky River, near Cleveland. The time is late afternoon. The sky is dull and cloudy. The sun shines clearly through the trees to the right. The camera is in the midst of trees. The spot is one that might be chosen for a picnic. Fig. 3a shows the vertical distribution of brightness. The most conspicuous feature is the much greater brightness of the sky than of the foreground.

Fig. 4, also at Rocky River, was taken later the same afternoon, after the foreground had passed largely into the shadow of the surrounding trees. With the deep blue and gray of the sky flecked with small bright clouds the scene was altogether a pleasing and restful one. There is here an even greater predominance of brightness in sky as compared with foreground (fig. 4a).

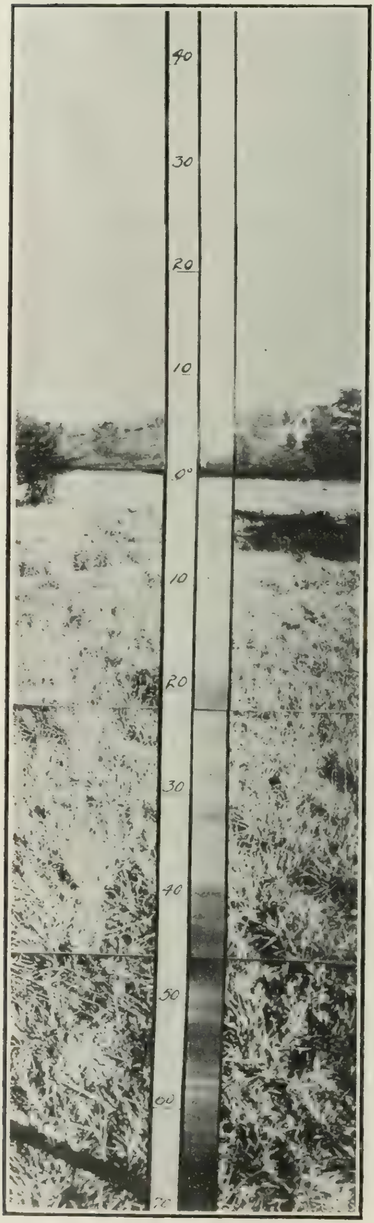


Fig. 5.—View in East Cleveland.

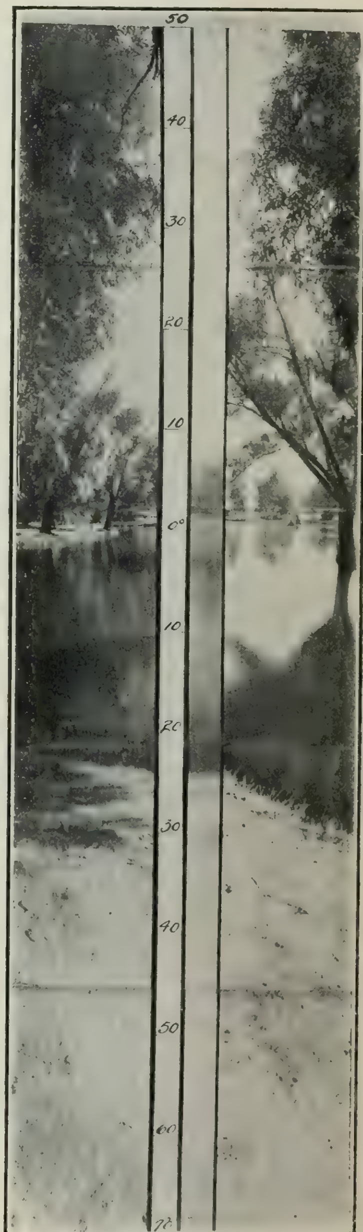


Fig. 6.—View in Wade Park, Cleveland.

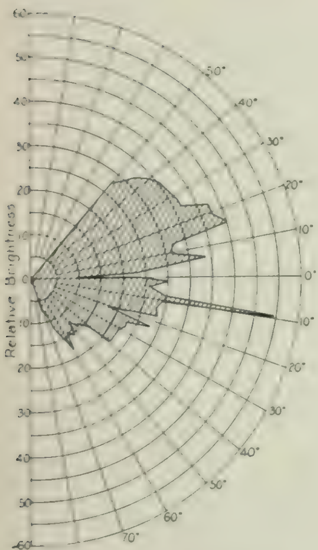


Fig. 5a.—Vertical distribution of brightness for fig. 5.

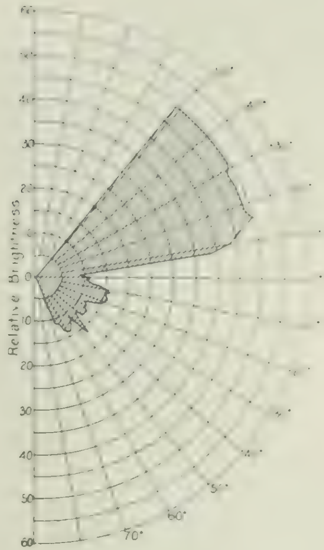


Fig. 5b.—Vertical distribution of brightness for fig. 5 (overcast day)

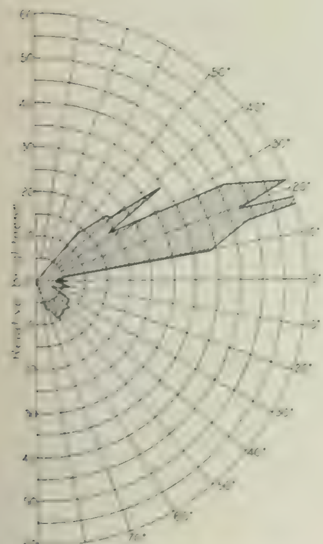


Fig. 6a.—Vertical distribution of brightness for fig. 6

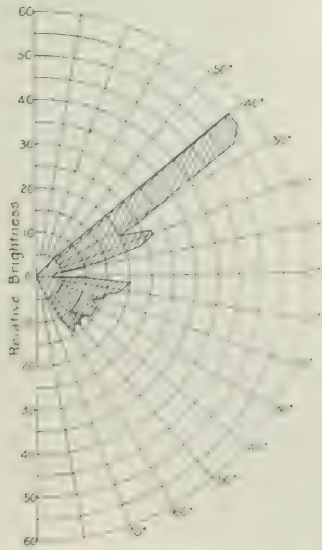


Fig. 7a.—Vertical distribution of brightness for fig. 7

Fig. 7.—Residence street in Cleveland.

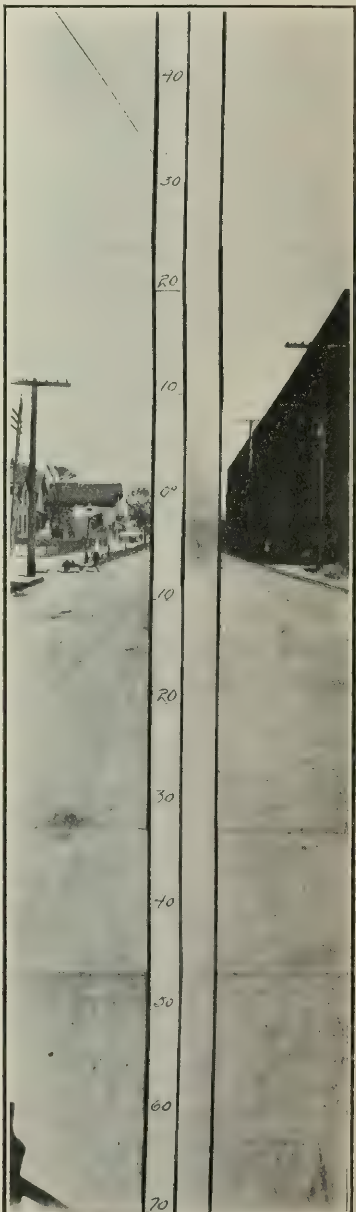


Fig. 8.—A Cleveland street.

Fig. 5 pictures a spot in East Cleveland, a low hill, with trees. High grass and dead leaves form the foreground. The sky is clear blue with a few light clouds. Behind the camera the afternoon sun illuminates the scene. The brightest spot is a little below the center of the picture, the two darkest in the shadows of the grass near the camera and in the trees near the center of the view. The sky presents the portion of most uniform brightness, while the total flux of light above the horizontal is somewhat more than that below. Except for one bright streak in the foreground, the sky for some distance above the horizon is the brightest part of the field of view. As the zenith is approached the brightness of the sky considerably decreases. Fig. 5b shows the distribution of brightness for the same scene on an entirely overcast day. The difference is most noticeable. From being only a little brighter as a whole than the foreground, the sky is now about four times as bright and much more of the total flux of light entering the eye comes from it than before. This, together with the shadowless condition mentioned above, makes the view on the overcast day unpleasant.

Fig. 6 is a photograph taken in Wade Park, Cleveland. It is late afternoon on a clear day, the sun to the side and rear of the camera. Here the most striking thing is the much greater brightness of the sky portions as compared with the foreground (fig. 6a), the difference being considerably greater than in the overcast day view just described. This was, however, a spot pleasant to the eye.

Fig. 7 shows a typical Cleveland street, such as thousands of people have to walk over every day. It can not be called entirely pleasant under the strong sun of August, yet the presence of trees and shade make it endurable. The picture was taken in the morning on a sunny day with a rather bright misty sky. The two chief characteristics are the dark point in the horizontal direction and the three- or four-fold brightness of the sky as compared with the foreground.

Fig. 8 is a view taken on an unshaded paved street in full noon sunlight on a clear day, with blue sky. This photograph was taken to illustrate the condition of intense glare from the pavement. Here the flux of light below the horizontal is greater

Fig. 9.—A Cleveland street.

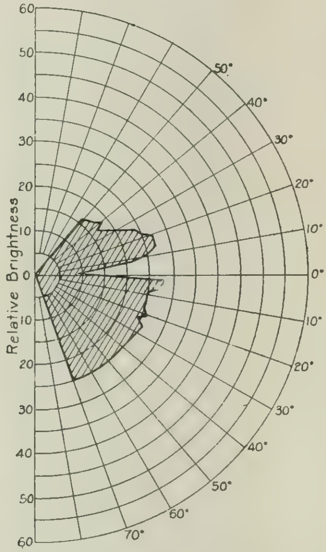


Fig. 8a.—Vertical distribution of brightness for fig. 8.

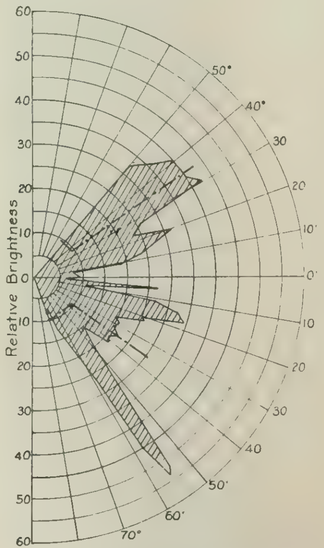


Fig. 9a.—Vertical distribution of brightness for fig. 9.

by several times than that above and the brightest part of the field of view is the foreground.

Fig. 9 shows another street view representing unpleasant conditions. Taken on a fairly clear day, early in the afternoon, it shows a light flux nearly equal above and below the horizontal, with the brightest spot in the foreground, the darkest in the horizontal direction. The point of interest about this picture is that if the observer steps back into a recessed doorway so that the immediate foreground and the upper portion of the sky are replaced by comparatively dark shadows the view becomes quite attractive. This is represented by the dashed lines in fig. 9a.

Generalizations from so few cases are difficult; many are not warranted. A few facts, however, seem to show clearly. One is that the eye will tolerate a greater brightness and flux of light above the horizontal than below. Thus the four pleasant cases (figs. 3 to 7) all show this peculiarity, while the street views with glaring conditions show the greater flux of light and the brightest spots below the horizontal. On the other hand the case of the overcast sky shows that the eye will not tolerate too great a flux above the horizontal. The fact of the matter seems to be that the unpleasant feature in each case is the presence of large areas of nearly uniform high brightness. The eye can tolerate such a condition in the case of the sky, as shown by figs. 3, 4, 5 and 6, but it cannot tolerate uniform high brightness in the foreground. In the case of the overcast sky (fig. 5b) the extended bright area of the sky does not appear to be pleasant, in apparent contradiction to the statement just made. The explanation seems to lie in the fact that in the sky, figs. 3, 4 and 6, there is considerable variety of light and dark due to foliage and clouds. In fact, as noted in the discussion of long shadows, the difference between pleasant and unpleasant conditions seems to lie chiefly in the presence or absence of variety. In the best landscapes studied by us the ideal condition seemed to be a preponderance of brightness in the sky, with a foreground showing marked varieties of light and shade, occasioned by the direct light of the sun falling rather obliquely. The diffused light of the sky alone is apparently not intense enough or properly directed to be of itself satisfactory for illuminating the foreground in the presence of an unbroken area of bright sky. The experiment

of observing the view shown in fig. 9 from within the shelter of a doorway illustrates some of the conclusions just drawn, for the area of uniform bright pavement surface is thereby decreased and a pleasing variety of light and shade is introduced.

Lumeter measurements were made during the course of the work in order to give some idea of the absolute values of the surface brightnesses and some of the ratios in question. Blue sky measured 2.2 c-p. per sq. in. A cumulus cloud in the same sky, 10.4 c-p. per sq. in. On an overcast rainy day the sky had a brightness of 3.3 c-p. per sq. in.; on a darker overcast day the brightness fell to 1 c-p. per sq. in. A cement pavement in sunlight had an intrinsic brightness of 6 c-p. per sq. in. A sunlit surface and the same surface in shadow show the relation between the direct and diffuse illumination to be about as three to one. The ratio between the brightest and darkest point of the averaged vertical distribution in the most varied landscape (fig. 6) is about 20 to 1. The brightest object measured was a white cloud which had about half the intrinsic brightness of a Welsbach mantle.

DISCUSSION.

Mr. G. H. Stickney:—This is an exceedingly valuable paper and not only opens up an important field of research, but also indicates a scientific method of procedure. It appeals to me especially because it presents ideas that I have felt to be true but never succeeded in analyzing or explaining. We have need of more work along this line.

Mr. Norman Macbeth:—I have seldom read a paper which has given me as much genuine pleasure as the one just presented. The points brought out, the methods used, and the suggestions following such an investigation are very interesting indeed. I feel that much real constructive work can be done along these lines, not alone with daylight but also in the analysis of artificial lighting conditions.

Dr. Hyde in his talk last evening referred to an architect who had expressed a thought that certain installation work in a church was almost sacrilegious. Perhaps some of the members here will remember a discussion I had in the New York section

some time ago with a member who was explaining how an interior could only be satisfactorily lighted from the standpoint of the architect, when that architect's conception and artistic feeling had been carried out in every respect, not only in the effect secured but also in the means of application. I had an argument develop rather suddenly when I mildly suggested an analysis of the results in a room with which the architect might be thoroughly satisfied, that we might more closely define in physical terms the architects feeling; with the thought that a variety of applications might be possible which would be effective to exactly the same extent.

Some of our members feel that an architect is supreme on all lighting problems where the exercise of artistic effort is concerned. That contention I grant willingly, and agree with thoroughly, but I do not feel that the architect insists upon being engineer and mechanic also. We are deeply concerned in the application and it was for this purpose that I suggested the analysis which I believe would be valuable unless the artistic feeling so frequently mentioned in discussions of this kind is indefinable and incapable of measurement.

I believe that when we get beyond the illuminometer measurements on horizontal planes, which have heretofore been more generally taken, and secure vertical measurements, measurements on inclined surfaces, brightness measurements of the walls, ceiling and floor, that we will be able to define our results very much more closely. I had some work here in Chicago within the past year in that line which was very interesting to me. In an investigation of some indirect lighting installations the observations taken were sufficiently complete to more fully admit of an analysis than would have been possible with the usual measurements on the horizontal plane. From the illustrations and descriptions which I have seen from time to time in advertising matter and elsewhere, I had the impression that indirect lighting resulted in a uniform high intensity on the ceiling, and from these tests I found quite a different effect. The ceiling was spotted and the less illuminated portions presented a considerable contrast to the brighter sections. In making horizontal measurements throughout the room, at each station the opal glass was removed from the illuminometer and the brightness measurement

taken of the ceiling directly above; the brightness of the walls was also investigated from the ceiling to the base and measurements were also taken of the floor brightness. I might add that we had no difficulty whatever in securing a balance against a buff wall nor even with the cork matting on the floor.

Investigation along these lines will bring out a great deal of valuable information which, as Dr. Ives says, "cannot be directly interpreted in terms of reflectors and lamps," but which will nevertheless be valuable to the commercial man and do much to set engineers right on subjects which to-day are unfortunately too often approached from the conversational standpoint.

Dr. H. E. Ives (in reply):—The good ship seems to have steered between the mines so successfully that there is no occasion for any closing remarks.

THE LAW OF CONSERVATION AS APPLIED TO ILLUMINATION CALCULATIONS.[1]

BY A. S. M'ALLISTER.

That the law of conservation is applicable in problems relating to luminous flux equally as well as in problems of other nature is self-evident. However, it seems well, at the outset of the present discussion, to show that the usual conceptions of the total effective flux density over the area illuminated as expressed by the so-called "cosine law" and "inverse-square law" give results in conformity to the law of conservation, in that the flux produced by the source is neither increased nor decreased until utilized for illumination, when it is transformed according to the well-established laws of nature.

GENERAL CASES.

Referring to fig. 1 consider the perfectly general case of a light source of any size or character situated in any position whatsoever within an enclosure having any possible shape or size. Select any infinitesimal section of the light source and determine the relation between the illumination produced upon any chosen small interior area of the enclosure and the illumination produced over the corresponding "solid angle" in the interior of an imaginary sphere having its center at the infinitesimal lighting source. The specific small area illuminated is assumed to be a section of the irregular enclosing surface of such infinitesimal dimensions that without any error whatsoever it may be considered as a plane making a definite angle with a radial line from the source; for illustrative purposes the small area (dA) is shown as a quadrilateral. Radial lines, from the source to the corners of the quadrilateral intercept the surface of the imaginary sphere and enclose thereon within the four points thus formed an infinitesimal quadrilateral area (da) subtending a "solid angle" exactly equal to the solid angle subtended by the selected small area on the irregular enclosing surface.

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

From simple geometrical relations, the correctness of which will be appreciated at once from a glance at fig. 1, it is seen that the areas bear to each other such a ratio that

$$(da) = \frac{r^2}{R^2} (dA) \cos \beta. \tag{1}$$

where β is the angle between a line normal to the area and a radial line from the source to the area. Consider that in the specific direction designated the infinitesimal light source has an

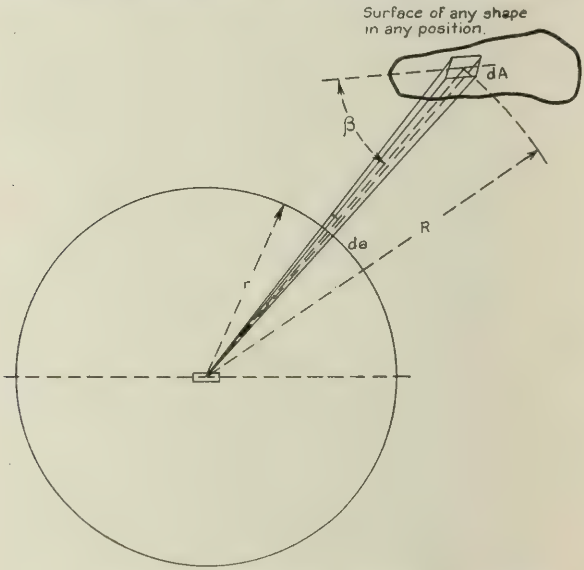


Fig. 1.—Photometric relations based on equality of solid angles.

apparent candle-power of (dc); then the normal illumination over the area (da) is $dc \div r^2$ and the total flux over this area is

$$\psi_a = \frac{(dc)(da)}{r^2}. \tag{2}$$

The normal illumination over the area (dA) is $(dc) \cos \beta \div R^2$ and the total flux over this area is

$$\psi_A = \frac{(dA)(dc) \cos \beta}{R^2}. \tag{3}$$

Combining equations (1) and (2) and comparing the result with equation (3), there is obtained

$$\psi_a = \frac{(dc)}{r^2} \times \frac{r^2}{R^2} (dA) \cos \beta = \psi_A. \tag{4}$$

The interpretation of equation (4), taking into consideration the facts upon which it has been based, is that, independent in every respect of the shape and size of the enclosing surface and the position of the light source within it, the flux integrated over any selected area depends solely upon the solid angle subtended by the area and the intensity of the candle-power in the direction selected. Thus the total flux emitted by each element of a lighting source is properly evaluated when the illumination normal to the enclosing surface is integrated over the whole interior surface, quite independent of the position of the light element within the enclosure. Since this relation is true for each element of a lighting source it is evidently true for the lighting source in its entirety.

It follows from the facts discussed above that in determining the total flux produced by any lighting source whatsoever the source can be assumed to be placed within any desired enclosure of any convenient size and the total flux (say in lumens) is properly represented by the integration of the illumination (say in foot-candles or meter-candles) over the whole surface (say in square feet or square meters). As a specific illustration, it may be stated that the total lumens from a mercury-vapor lamp of any size can be ascertained with absolute accuracy by taking observations of the illumination on the interior of an enclosing sphere of any diameter whatsoever—ignoring the error in photometric measurement which may be attributable to the Purkinje effect. Moreover, so far as concerns the determination of the total flux—but not the candle-power in each direction in space—the mercury-vapor lamp can be treated as a point source of light when photometered from any distance whatsoever even if no greater than the distance from the center of the tube to its terminals. Furthermore, the assumed central point can be located arbitrarily, without any reference to the location of the lamp itself. That is to say, the determination of the total luminous flux from a light source of any size or character whatsoever is a thoroughly definite problem easy of exact solution when based on the law of conservation.

An interesting and valuable relation between light flux and solid angle is found in the converse of the above demonstration. That is, instead of finding the constancy of the total flux from a

chosen source within a given solid angle, and hence a flux density varying inversely with the square of the distance from the source and the cosine of the angle of inclination of the illuminated surface, it is appropriate to demonstrate the constancy at any chosen point of the illumination produced by a surface lighting source of a certain normal emitting illuminating density subtending a certain solid angle, quite independent of the shape or inclination of the source or its distance from the point under consideration.

Referring again to fig. 1, let (dA) be a small section of a lighting source of any shape or inclination situated at any distance whatsoever from the point shown as illuminated by this source. Let c be the normal emitting density (here used as apparent candle-power per unit area) of this source. The illumination produced at point indicated, from the inverse square and cosine laws, is,

$$\beta_A = \frac{c(dA)\cos\beta}{R^2}. \tag{5}$$

Consider now the illumination produced at the same point by the surface source (da) subtending the same solid angle as (dA) and having an equal normal emitting density c. The illumination at the central point is

$$\beta_a = \frac{c(da)}{r^2}. \tag{6}$$

Combining equations (1) and (6) and comparing the result with equation (5) there is obtained

$$\beta_a = \frac{c(dA)\cos\beta}{R^2} = \beta_A. \tag{7}$$

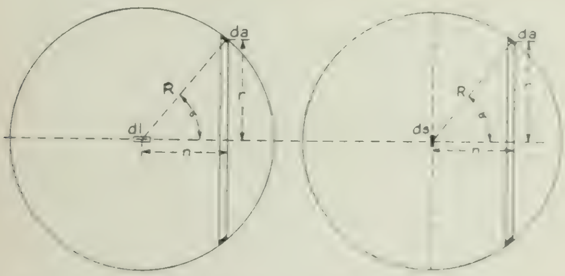
Equation (7) shows that when dealing with surface lighting sources the illumination at any chosen point is fully defined when the emitting density of the source and the solid angle subtended by the source, as viewed from the point chosen, are known. Upon this fact can be based some extremely simple graphical solutions of problems relating to surface lighting sources, provided the law of conservation is kept always in mind and properly applied.

Of the many possible surfaces for enclosing lighting source the one lending itself most readily to simple solution is the

sphere, by reason of the ease with which the superficial areas and solid angles can be evaluated. It may be well, therefore, to show the more important relations existing between the flux, flux density, apparent candle-power, etc., when linear, curved and plane surface light sources are placed within spherical enclosures.

SURFACE LINE SOURCE.

Fig. 2 represents the case of a "surface line source"—such as a mercury-vapor lamp is usually assumed to be—within a spherical enclosure. Attention should here be called to the fact that the "surface line source" differs from the "point line source" in that it is a cylindrical surface source of zero diameter, instead of consisting of an infinite number of point sources arranged in one line. Thus the so-called cosine law which is applicable to



Figs. 2 and 3.—Photometric relation of infinitesimal surface line and plane surface sources.

the plane or curved surface source is also applicable to the surface line source. With an apparent candle-power of (cdl) per unit length in a radial direction—that is, 90 degrees from the line—the apparent candle-power in a direction α degrees from the line is $(cdl)\sin\alpha$.

Over the area (da) in fig. 2 the flux density is

$$\beta = \frac{(cdl)\sin\alpha}{R^2}. \tag{8}$$

and the total flux over the area (da) is

$$d\psi_{dl} = \frac{(da)(cdl)\sin\alpha}{R^2}. \tag{9}$$

Now

$$a = 2\pi R^2(1 - \cos \alpha), \tag{10}$$

and

$$da = 2\pi R^2 \sin \alpha d\alpha. \tag{11}$$

Hence

$$d\psi_{dl} = 2\pi R^2 \sin \alpha d\alpha\ (cdl) \sin \alpha \div R^2 = 2\pi(cdl) \sin^2 \alpha d\alpha. \tag{12}$$

The total flux produced by the elementary light line (dl) over the whole of the two hemispherical areas is

$$\psi_{dl} = 2 \int_0^{\frac{\pi}{2}} 2\pi(cdl) \sin^2 \alpha d\alpha = \pi^2(cdl) . \tag{13}$$

The flux produced by a line having a length l, is evidently

$$\psi_l = \pi^2 cl. \tag{14}$$

If the candle-power of the elementary line source had been (cdl) equally in all directions the total flux from the line of length l would have been 4π instead of π^2 The spherical reduction factor of the "surface line source" is therefore,

$$\pi^2 \div 4\pi = 0.7854, \tag{15}$$

which is the value by which the average "radial candle-power," as observed on very small isolated lengths must be multiplied in order to ascertain the "mean spherical candle-power" of the whole "surface line source."

PLANE SURFACE SOURCE.

Another simple case is that of the plane surface source, as illustrated in fig. 3. The flux over the area (da) produced by the small lighting surface (ds) having a maximum apparent candle-power radially of c per unit area is

$$d\psi = (da)(cds) \cos \alpha \div R^2, \tag{16}$$

as shown in equation (11),

$$da = 2\pi R^2 \sin \alpha d\alpha,$$

hence

$$d\psi = 2\pi(cds) \sin \alpha \cos \alpha d\alpha = \pi(cds) \sin 2\alpha d\alpha \tag{17}$$

and

$$\psi = \pi(cds)\int_0^{\frac{\pi}{2}} \sin 2\alpha d\alpha = \pi(cds). \qquad (18)$$

The value given in equation (18) relates to the total flux in the right-hand hemisphere, but it also represents the value for the whole sphere because the source produces no flux in the left-hand hemisphere. If the source produced candle-power in all directions equal to (cds) the total flux would be $4\pi\,(cds)$. Hence the value by which the maximum apparent candle-power of a small plane surface source must be multiplied to obtain the mean spherical candle-power of the source is

$$\pi(cdl) \div 4\pi(cdl) = 0.25. \qquad (19)$$

SPHERICAL SURFACE ILLUMINATION.

An important relation in spherical photometry is found in the fact that a surface lighting source at the inner edge of any sphere produces an illumination density normal to the interior surface of the sphere which is every where equal. This fact will be easily appreciated from a study of fig. 4 where the infinitesimal surface lighting source is shown at O. Let it be assumed that this source of area (ds) has an apparent radial candle-power of (cds). The apparent candle-power along the direction OP will be $(cds)\cos\alpha$. At the point P the light flux density in the direction parallel to the line OP is $(cds)\cos\alpha \div r^2$ while the density normal to the sphere at this point is

$$\beta_P = (cds)(\cos\alpha \div r^2)(\cos\alpha) = (cds)\cos^2\alpha \div r^2. \qquad (20)$$

Now $\qquad r = D\cos\alpha$, so that,

$$\cos^2\alpha \div r^2 = 1 \div D^2. \qquad (21)$$

hence

$$\beta_P = (cds) \div D^2. \qquad (22)$$

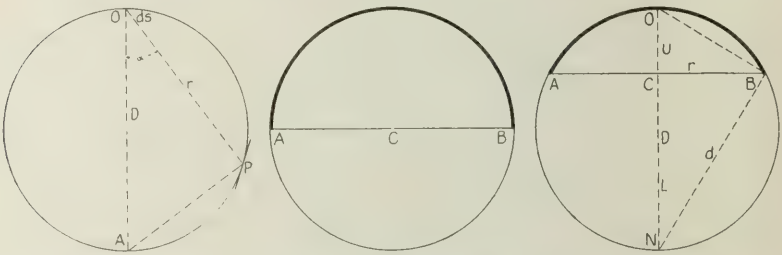
According to equation (22) the normal light flux density is uniform over the whole inner surface of the sphere illuminated by the source; the numerical values of the illumination (in foot-candles or meter-candles) is found at once by dividing the total apparent radial candle-power of the source by the square of the diameter of the sphere (in feet or meters).

If it be assumed that the lighting source is of infinitesimal size so that the illuminated area is equal to the whole interior surface of the sphere, then the total lumens reaching the illuminated surface, which by the law of conservation must equal the lumens from the source, have the value

$$\psi_t = \pi D^2 \beta_P = \pi D^2 (cds) \div D^2 = \pi (cds). \qquad (23)$$

The value for the flux given in equation (23) is seen to be identical with that given in equation (18)for the same quantity determined on the basis of the more usual photometric relations.

In applying the law of conservation of lumens to problems relating to plane and curved surfaces a certain fact, which may not be immediately apparent, must not be overlooked, namely,



Figs. 4, 5, and 6.—Equality of flux and flux density over equilux spheres.

some of the light emitted by one radiating surface may fall upon another radiating surface where it may be either absorbed or reflected. In fig. 5, for the purpose of simplest demonstration, the radiating area is assumed to cover exactly one half of the interior of the sphere, the interior of the upper hemisphere having a radiating value of I lumens per unit area. The lower hemisphere is illuminated solely by the upper hemisphere and the problem is to determine how many lumens there are per unit area in the lower hemisphere.

At first glance it might appear that since the radiating area is equal to the illuminated area, the law of conservation would require the upper hemisphere to give off exactly the same number of lumens per unit area as fall upon the lower hemisphere. Such is not the case, however. The facts are that the lumens from each element of the radiating area are distributed over not only the lower hemisphere but over the upper hemisphere as well; of

the total lumens produced, one half falls upon the upper hemisphere leaving only one half to illuminate the lower hemisphere. Since each element of the radiating area spreads its lumens uniformly over the whole spherical interior, it follows that the lower hemisphere is uniformly illuminated with a density one-half of that of the upper radiating area.

It is worthy to note in this connection that if the upper hemisphere have a light-absorbing coefficient of 100 per cent. the total emitted radiation must be just double the value reaching the lower hemisphere; on the other hand, if the upper hemisphere have a reflecting coefficient of 100 per cent. then one half of the apparent brightness of the surface would be due to reflection and only one half would be original emission. In any event, whatever may be the coefficient of reflection or absorption, all the lumens passing through the (great circular) area separating the upper from the lower hemisphere reach the lower hemispherical area over which they are distributed uniformly. Incidentally, it may be noted that the projected area (the great circle) of the upper hemisphere as viewed from any point on the interior of the lower hemisphere is equal to one half of the interior area of the lower hemisphere—a fact that will be enlarged upon below.

PLANE CIRCULAR SOURCES.

Consider now the more general case illustrated in fig. 6 in which the upper radiating zone has a height U, and the lower illuminated zone a height L, the diameter of the sphere being $D = U + L$. The inner surface area of the upper zone is πDU and that of the lower zone πDL. With l lumens radiated per unit area, the total lumens radiated equal πDUl which are uniformly spread over the whole area πD^2, so that the illumination density is

$$\frac{\pi DUl}{\pi D^2} = \frac{Ul}{D}. \tag{24}$$

The lumens leaving the upper zone through the circular opening and reaching the lower zone equal

$$\psi_L = \frac{\pi DL \times Ul}{D} = \pi ULl. \tag{25}$$

Since the triangle OBC and BCN (fig. 6) are similar,

$$OC : BC = BC : NC, \tag{26}$$

hence

$$\overline{BC}^2 = \overline{NC} \times \overline{OC} = UL, \tag{27}$$

combining equations (25) and (27),

$$\psi_L = \pi ULl = \pi\overline{BC}^2 l \tag{28}$$

Now $\pi\overline{BC}^2$ is equal to the area of the circle ABC, and hence it may be stated that the lumens reaching the lower zone are the same in value as the amount which would be produced by a plane surface source equal in area to the circle separating the radiating from the illuminated area and having the same radiation constant per unit area as has the source. That is to say, the total luminous flux produced over the lower zone is the same whether the radiating surface is the complete upper zone or the plane circular area separating the upper from the lower zone. Moreover, the distribution of illumination over the lower zone is identical in the two cases, as a reference to equation (7) will show.

From the law of conservation, the illumination (in lumens per unit area) over the lower zone bears to the emitted lumens per unit area of the plane circle the inverse ratio of these two areas.

The area of the plane circle is πr^2 and that of the lower zone is πDL,

From fig. 6, $$L = d \cos ONB,$$

$$d = D \cos \overline{ONB},$$

hence

$$DL = d^2,$$

and

$$\pi DL = \pi d^2. \tag{29}$$

The ratio of the radiating and the illuminated areas is

$$\frac{\pi r^2}{\pi d^2} = \frac{r^2}{d^2}. \tag{30}$$

which is the ratio between the luminous flux densities on the two areas. If the radius of the circular source is taken as the unit of length and the emitting flux density of the source is taken as the unit of illumination, then the value of the normal illumination over the sphere expressed in per cent. is equal to 100 divided by the square of the diagonal d. This relation holds true over the entire area of each of any conceivable number of spheres

passing through the edges of the plane circular source, and by constructing any desired number of such "equilux spheres" one can easily explore the whole luminous region surrounding the source, which may be—for example—a diffusing artificial window in a ceiling, or side wall.

ILLUMINATION ON EQUILUX SPHERES AND ON HORIZONTAL AND VERTICAL PLANES.

In fig. 7 are shown relative space positions of, and values of illumination in per cent. of the source density normal to, 18 equilux spheres passing through points vertically below the center

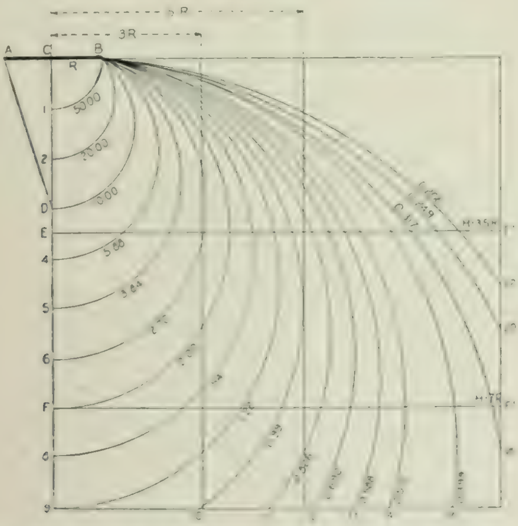


Fig. 7.—Normal flux densities in per cent over equilux spheres

of a circular source at distances equal to 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 18, 20, and 22 times the radius of the source. It can easily be shown by simple geometrical constructions that the illumination density normal to any horizontal plane below a circular source in the ceiling is at each point equal to the "equilux sphere" illumination at that point, so that the values of illumination density in per cent. marked on each of the equilux spheres in fig. 7 are also the values of normal illumination on any horizontal plane intersecting these spheres.

In fig. 7 intersecting horizontal planes are shown at distances of 3.5 and 7.0 radii below the source. The normal flux densities on these planes are shown to rectangular coördinates in fig. 8.

At points on any vertical plane as far below the source as this plane is distant from the center of the source in the normal nearest direction, the illumination normal to the vertical plane at the point is equal to that normal to the horizontal plane at this point. At all other points the normal illumination on the vertical plane bears to the normal illumination on the horizontal plane at this point, the ratio of the distance of the vertical to the distance of the horizontal plane from the center of the source,

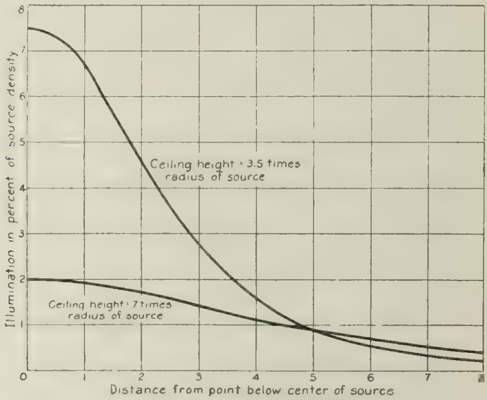


Fig. 8.—Flux densities on planes 3.5 and 7.0 radii below circular ceiling source.

each distance being measured in a direction normal (shortest) to the plane considered. When solving problems relating to plane circular lighting sources by means of the equilux spheres one can easily determine the illumination normal to any horizontal plane and can then calculate the illumination on any vertical plane by direct proportion.

It is believed that the above method represents the extreme of simplicity for the solution of problems relating to the illumination obtained from plane circular lighting sources, and it is probably true that the error involved in treating rectangular surface sources as equivalent to circular sources of equal area would prove of small importance in practical engineering undertakings.

The error involved would relate to the distribution of the flux and not to its total value, which would be the same in the two cases, according to the law of conservation.

ABSORPTION OF LIGHT.

In the above discussion the effect of reflection from the illuminated surfaces has been ignored, as is the custom in dealing with problems of the nature under consideration. That is to say, all of the illuminated surfaces discussed have been treated as possessing a light absorption coefficient of 1.00, as is tacitly done in almost all illumination calculations. In view of the ease with which reflection or absorption can be taken in consideration on the basis of the law of conservation, it is truly astonishing that so little application has been made of this law in this connection.

According to the relations discussed above the total flux in lumens (4π spherical candles) which the lighting units must produce within a given enclosure having surfaces of 1.00 absorption coefficient is numerically equal to the summation of the flux density (in foot-candles or meter-candles) over the separate areas (in square feet or square meters). This method of determination is absolutely accurate. An equally accurate method is available for use with totally or partially reflecting surfaces, in that the lighting units in any case whatsoever must produce only that amount of lumens absorbed by the enclosing surfaces. It follows, therefore, that when the incident flux density over each surface is multiplied by the absorption coefficient for this surface and a summation is made of the lumens thus absorbed by the various surfaces enclosing the lighting units, the result is an absolutely accurate determination of the lumens which the lighting units must produce. This method can be applied with complete assurance that the results are correct to the same degree that the areas, incident flux densities, and absorption coefficients assumed are correct.

The absorption-of-light method of calculation shows at once the total lumens or mean spherical candle-power required to obtain any specific illumination results, but does not completely define the required space distribution of the candle-power of the units in order to insure the results desired. However, there are certain limits of inter-reflection between facing surfaces,

depending upon the individual absorption coefficients, which a simple application of the method will make evident at once.

It is believed that, by reason of its accuracy and simplicity, the absorption-of-light method, which is based directly upon the law of conservation, can well be applied in numerous illumination problems, at least as a trustworthy check upon the more complicated methods now in common use.

DISCUSSION.

Prof. W. E. Barrows, Jr.:—I wish to express my high appreciation of not only this paper of Dr. McAllister's but of others which he has published from time to time along these same lines. No one can dispute the fact that the society and the profession have been greatly benefited by his earnest endeavors and untiring efforts to advance the cause of the engineer.

Just before the meeting I thought I had discovered a slight error in the first figure of the paper. I would like to follow my reasoning at this time to see if there is not a mistake. Referring to fig. 1 the author states the area da is equal to $\frac{r^2}{R^2}(dA)\cos\beta$. Now if the area dA be normal to the lines of the light flux, then, in that case, the angle β would be 90 degrees, the cosine of which would be zero, whereas it should be unity.

Dr. A. S. McAllister:—The angle β in fig. 1 can be considered as the angle between the plane area dA and a radial line from the source, or it can be considered as the angle between a line normal to this plane and a radial line from the source—the perspective not being well defined in the illustration. In case the former is chosen, the function used in equations (1), (3), (4), (5) and (7) should be sin β, while when the latter is assumed the corresponding functions should be cos β, as have been used by the author. (This fact is pointed out more clearly in the final paper than in the advanced copies.) It is noteworthy that the final results obtained by the two assumptions considered separately are identical.

Prof. W. E. Barrows, Jr.:—There are several interesting facts brought out in this paper which are not elements of common knowledge and which are not likely to be considered as bear-

ing the relations to one another that are shown here. Among these is the identity in the treatment of the calculations of light from a luminous source resembling an interior spherical surface and a flat circular surface source having the same periphery as the opening of the spherical source. Again Dr. McAllister has shown that the mean spherical candle-power from a "surface line source" is $\pi/4$ times the maximum candle power; while from a plane surface source the mean spherical candle-power is one-fourth multiplied by the maximum candle power, or $1/\pi$ times the former.

It seems to me that this paper emphasizes the desirability of endeavoring to employ the lumen in describing the performance of a luminous source and in making illumination calculations. It is a very convenient unit; it does away with the uncertainty of candle-power values which may be maximum, horizontal, mean hemispherical or mean spherical values. If the results are given in lumens there is little chance for confusion and the total amount of light is represented. In the case just cited we have a concrete example. The maximum candle-power values are the same but the total amount of light is as 1 to π.

Dr. M. G. Lloyd:—I want to express my appreciation of this work, because I think it gives a very excellent short-cut method in getting a great deal of the data that is needed for the flux in different parts of ceiling, floor and wall surfaces. I am sorry I have not had an opportunity to study it carefully, but I have only looked over it rather hastily; and I am sorry I can't see anywhere a statement of what is meant by this law of conservation. I confess that I don't know what that law is. I mention it in the hope that Dr. McAllister will explain it in closing the discussion. If that expression is used in the ordinary sense of the term, in representing that there is no loss of light as it passes from a source to the eye, I can't accept it as a law of nature because that is not so.

In New York, I believe if one gets on top of the Singer building, or any other high building, he can easily see up to Harlem, or points beyond, but if Dr. McAllister were used to the Chicago atmosphere and would consider a source of light, say over at the stock yards, and just follow out a solid angle from that point

over to this hotel, he would find that he would not receive as much light here as passes through some of the intermediate surfaces. In other words, we have absorption of light. The amount of flux of light which leaves a source is not actually equal to the amount of light that falls on each surrounding surface. If that is what is meant here by the law of conservation, it certainly is not a law of nature. Practically, of course, in very many cases the absorption is negligible, but I don't think such an approximation should be stated as a law; it is simply a special case when the absorption is negligible.

When we speak of the conservation of energy or of matter, we express by that term our belief that energy or matter cannot be destroyed as such; it can only be transformed into energy or matter of a different kind. If conservation is used in this sense, light is certainly not conserved, since it can be destroyed. If, on the other hand, by conservation of light it is meant merely that light persists as such until it is destroyed, we are stating no law of nature, but merely an axiom of existence. Of course a thing exists until it ceases to exist.

Coming down to some of the later derivations, however, such as in figure 5, I am not able to follow the reasoning entirely. Referring to that figure, in which the source of light is one half of the sphere, the author says, "It follows that the lower hemisphere is uniformly illuminated with a density one half of that of the upper radiating area." He seems to have stated in one place that the two halves were equally illuminated. It seems to me that point needs some elucidation. I don't know whether, in considering the flux through an area which is a source, the author considers both flux coming out and going in. If he is considering only the flux impinging on the surface, he has just demonstrated it was equal at all points of the surface. If he considers it algebraically, in and out, the statement would still not be correct. And if he considers the sum of the impinging light and that emitted by the surface then the upper half of the sphere should be credited with one and one half units as against one half for the lower hemisphere, or the ratio is three to one.

A little lower down, considering a surface having a reflect-

ing coefficient of one hundred per cent., it seems to me that would represent one which would have zero emissive power, so that is could not represent any possible condition. Assuming, however, that a surface could both emit and perfectly reflect, the light from any point on the upper hemisphere would be represented by one and one half units, the one half being due to reflection and the one unit to emission, and consequently two thirds of the apparent brightness would be due to emission and only one third to reflection.

However, these points are not essential in any way to the main purpose of the paper, which seems to me excellent, and the method given should be very valuable, since it is a short-cut method.

Dr. A. S. McAllister (in reply):—In his hasty reading of the paper the last speaker misinterpreted the title and overlooked the explanation thereof given in the first paragraph. A careful reading of the paper will show that it was the author's intention to discuss the extent to which the general law of conservation is applicable in problems relating to the calculation of illumination; and to show that, in so far as the so-called "cosine law" and "inverse-square law" are applicable, it is absolutely accurate to calculate the flux produced by the source by taking the sum of the fluxes absorbed by the medium illuminated. The paper does not contain the statement that the flux is conserved, but rather that its value is "neither increased nor decreased until transformed, according to the well-established laws of nature." If the general law of conservation can not be referred to in this connection, then it is wrong to refer to it in connection with chemical energy, electrical energy, or any other specific form of energy, which is not conserved but merely retains its value unaltered until transformed.

If a certain floor for example were covered with dust one could not determine the illumination on the floor surface proper without taking into consideration the absorption of light by the dust. If this dust were distributed uniformly through the atmosphere between the light source and the plane which it was desired to illuminate one must certainly take into consideration the absorption by the dust—if such absorption is of any import-

ance. Such details are never considered in applying the "inverse-square law" and it seems unnecessary to introduce them in the present paper. However, to assume that the general law of conservation is not applicable in problems relating to light flux which may be transformed in part before reaching the planes to be usefully illuminated, would be identical with assuming that the general law of conservation is not applicable in problems relating to chemical energy which may not all be usefully employed.

Dr. Lloyd is correct in his statement concerning the impossibility of finding any medium having a 100 per cent. reflection coefficient with any chosen value of emission. However, he failed to note that the author purposely assumed the two extreme conditions of 100 per cent. reflection and 100 per cent. absorption in order to call attention to the fact that the problem under discussion is perfectly general and the solution is the same, independent of the actual value of absorption or reflection. His statement relative to the ratio of the incident illumination density in the lower hemisphere of fig. 5 and the apparent emission density when the upper hemisphere has a 100 per cent. reflection coefficient—the lower hemisphere being tacitly assumed to have 100 per cent. absorption—does not accord with the author's ideas of the photometric relation involved.

It is self-evident that with a total apparent upper hemispherical emission density of any chosen value whatsoever the lower hemispherical incident illumination density has a definite determination value independent in every respect of the relative values of the fluxes obtained directly and by reflection from the upper hemisphere. If the upper hemisphere has 100 per cent. absorption—zero reflection—and the total emitting density is 1.5 units then, as proved in the paper, the lower hemisphere receives 0.75 units of illumination density. Obviously this identical ratio of two to one would hold for any relative values between direct and reflected light in the upper hemisphere; the apparent emission density depends only upon the sum of the direct and reflected light and not on the subdivision of the total light. Considered specifically if the actual initial light production in the upper hemisphere is one unit per unit area over the whole hemispherical surface, and the reflection coefficient of the

upper hemisphere is 100 per cent.—the lower hemisphere having 100 per cent. absorption— then the directly emitted light flux which reaches the lower hemisphere in 0.50 unit per unit area. One half unit of direct light flux reaches each unit area of the upper hemisphere itself: this 0.50 unit flux per unit area in the upper hemisphere is redirected to the upper as well as to the lower hemisphere; the 0.25 unit of redirected light which reaches each unit area of the upper hemisphere is again redirected to the upper as well as to the lower hemisphere, etc., until the total upper apparent emission density is 2.0 units and the lower incident illumination density is 1.0 units. The summations of the direct, reflected, re-reflected, etc., light density over the upper hemisphere and the corresponding incident light flux density over the lower hemisphere are as follows:

Upper density, 1.0 + 0.5 + 0.25 + 0.125 .... = 2.0
Lower density, 0.50 + 0.25 + 0.125 + 0.0625 .... = 1.0

The above discussion is covered in the paper by the statement that if the upper hemisphere have a reflection coefficient of 100 per cent. then one half of the apparent brightness of the surface would be due to reflection and only one half would be original emission.

RESUME OF LEGISLATIVE ENACTMENTS ON ILLUMINATION.[1]

BY E. LEAVENWORTH ELLIOTT.

JUSTIFICATION FOR LEGISLATIVE REGULATION OF ILLUMINATION.

Not only the right, but the duty of government to enact measures for protecting the health and physical welfare of the citizens, and especially those engaged in manual labor, is now universally recognized. As any restriction upon personal liberty suggests in some measure parental authority, all legislation looking to this end in this country has encountered the instinctive dread which the American has to "paternalism" in government. This objection, however, is wholly sentimental. The very essence of government is the exercise of wise control over acts of both commission and omission involving the general good; and it may be truthfully said that the nearer which a government approaches the methods of the strong, but wise and thoughtful parent the better it will be.

The days of Robin Hood, Dick Turpin, and the western "road agent" are past; modern government says that you may not take your neighbor unawares and use the bludgeon or the revolver as an argument, even though you present these arguments in the most Chesterfieldian manner. It is an entirely logical consequence of this view of the duty and function of government in protecting its citizens from bodily violence that it should say to the employer, "you may not impair or destroy the health of your operatives by requiring them to work in rooms not properly supplied with the natural conditions for labor, the two most essential of which are light and air." Hence, all civilized governments having any claims to enlightenment have enacted laws prescribing to a greater or less extent the physical conditions under which labor may be employed; and there is a very strong tendency, backed by public opinion, to increase the restrictions

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

and regulations as fast as a thoroughly established basis for their formulation can be secured.

In this country the prejudice against paternalism in government is still so strong that many of the reforms which are taken up directly by government in other countries are carried on here by voluntary associations, the large number of which, and the success of whose work, is one of the most important phenomena in our recent social development. For example, the national association which has been working for several years to stamp out tuberculosis has made such progress that there seems to be little doubt that it will have practically blotted out this plague of civilization long before the half century mark shall have been passed.

AGENCIES PROMOTING LEGISLATIVE REGULATION IN AMERICA.

The American Association for Labor Legislation is actively working for the improvement of laws relating to the welfare of the laborer. This association has become deeply interested in the question of illumination as affecting industrial hygiene, and will further, by all means in its power, legislation looking to the proper regulation of lighting conditions.

The American Association for the Conservation of Vision was organized in March and incorporated in June of this year. The work of this association is divided into six departments, two of which are concerned with illumination, viz., the industrial and educational departments, the former dealing with all problems affecting the care and use of the eyes in the industries, and the latter the hygiene of the eyes in schools and institutions. Each department consists of a director, and as many associates as may be deemed expedient. Dr. Louis Bell has accepted the directorship of the industrial department, and has chosen a number of prominent oculists among his associates.

An important part of the work of this department will be the determination of such requirements in industrial lighting as may be considered standard and fundamental, and which may thus serve as a basis for legislation. To this end, the department will coöperate with all existing bodies dealing with any phase of the subject. A committee of the American Medical Association, of which Dr. William Campbell Posey of Philadelphia is chair-

man, is investigating the physiological aspects of industrial lighting. The Manufacturers' Association has a committee investigating particularly the economic side of the question. With these and others working in the same line the industrial department will actively coöperate, the purpose being to gather data and information from all available sources, and where there are still gaps in the chain of evidence to have special investigations conducted to supply the deficiency. From this collected knowledge the department can then standardize practises and formulate just and reasonable requirements for legislation.

There are two organized forces, then, in this country working directly toward legislative regulation of illumination, viz., the American Association for Labor Legislation, whose business it is to directly instigate and promote the passage of legislation, and the American Association for the Conservation of Vision, whose purpose is to supply as an impartial authoritative source a standard of practise as a basis for such legislation. The various scientific societies, particularly the Illuminating Engineering Society and the ophthalmological societies, are natural tributaries.

The question may arise, why should not the Illuminating Engineering Society be the principal rather than the second in the work of promoting legislation on illumination? There is a good and sufficient reason: the Illuminating Engineering Society, ostensibly at least, is an association of professional engineers. It is self-evident that, from the ethical standpoint, men cannot do collectively what they could not properly do as individuals. Were an illuminating engineer to seek the enactment of legislation requiring specified conditions of lighting in the industries or elsewhere he would be open to the charge of seeking class legislation which would directly benefit himself and his confreres. For the same reason neither the association collectively, nor its members individually as professional men, can advertise or use other means of public education to promote better practises in lighting. Such publicity work, of which influencing legislation is a part, can be ethically carried on only by social organizations, the membership of which has no commercial interest, directly or indirectly, in the objects of its endeavor. The same logic applies to the ophthalmological and other professional and scientific societies. While these may be properly looked to as sources of

scientific knowledge and reliable data, publicity and legislation must be left for the social or humanitarian society.

STATUS OF LEGISLATIVE REGULATION OF ILLUMINATION IN AMERICA.

The following resume of legislation in this country is taken from an article on factory lighting, contributed by the author to the *American Legislative Review*,[1] which is the official publication of the American Association for Labor Legislation:

There are only eleven states that make any mention of the subject of light in their general factory or labor laws, and in not one of these are the provisions sufficiently specific to render them of practical value.

Connecticut provides that factories be "well lighted," and that colored and corrugated windows may be removed if injurious to the eyes. Illinois requires halls, stairways, etc., to have lights kept burning whenever the building is in use. Maryland requires factories to be "well and sufficiently lighted." Michigan requires foundries to be "reasonably well lighted throughout working hours," and grinding and polishing cannot be done in basements unless sufficient light, heat, and ventilation are provided, as prescribed by the factory inspector. In Missouri, Rhode Island, Ohio and New Jersey, if the Commissioner of Labor, or inspector, finds the heating, lighting, ventilation, or sanitary arrangements dangerous to health, he is to give notice to make necessary alterations. New York and Oklahoma require workrooms, halls, and stairways leading to them, to be properly lighted. Pennsylvania has the same requirement, together with the provision, giving the inspector power to require alterations where lighting is not sufficient.

CONDITION OF LEGISLATION IN EUROPE.

The American Association for Labor Legislation has its counterpart in most European countries. So far as the author is aware, these associations have not as yet actively promoted legislation in regard to industrial lighting, but they probably will follow the example set by the American Association.

The second Congrès Internationcle des Maladies Professionnelles, held in Brussels last year, considered the subject of lighting, a paper being presented by Mr. Leon Gaster.

The subject was later brought to the attention of the British home office, and the chief factory inspector was directed to investigate the subject of industrial lighting with reference to legislation.

The question of illumination in connection with ventilation was taken up by the Commission on Public Health in the Third

[1] *Am. Leg. Rev.*, vol 1 p. 11.

District of Paris in 1904, who brought the matter to the notice of the Minister of Commerce and Industry. The regulations put in force in 1894 stipulated that "Confined work shops in which employees are constantly at work must not be crowded*** These premises, especially passages and staircases, must be suitably illuminated." Later in the same year the general regulations were more definitely stated. The question then arose as to whether this general requirement that premises be suitably illuminated was sufficient, and the matter was referred back to the Commission on Public Health. The following extracts from the report of this commission are from the translation in the *Illuminating Engineer,*[2] London, which gives a general résumé of legislative enactments in the different European countries:

The use of artificial light leads to two sources of inconvenience to the worker. The light fatigues the vision, and in addition, works in which artificial light is employed leave something to be desired from the hygienic standpoint in other respects. Let us consider these two questions.

From the point of view of convenience to eyesight no conditions equal those existing when the work is carried out by proper daylight illumination. Close to a window from which a large sky area is visible, the average illumination on an ordinary day, leaving out of account the direct rays of the sun, may amount to forty or fifty lux.[3] This order of illumination is that which general considerations suggest is desirable for the ordinary classes of work.

The artificial illumination provided may vary in intensity, in quality, and in the method of distribution. As regards intensity, it may be suggested that in favorable circumstances good conditions are represented by an illumination of the order of fifteen lux, even in the case of works devoted to sewing or printing. In a spinning factory a value of five lux may be suggested.

In addition the quality of the light available varies very greatly, according to the degree of incandescence[4] of the sources employed.

In the case of an artificial source of light of specified intensity,[5] a high percentage of the less refrangible rays from the yellow onward promotes visual acuity, but adds little to the integral brightness of the source. On

[2] *Ill. Eng. London*, vol. 2, p. 319.

[3] By "lux" is understood the illumination corresponding to normal incidence, and caused by the rays from a source of intensity 1 bougie-decimale, *i. e.*, 1/20 of the Voille standard, at a distance of 1 meter.

[4] The "degree of incandescence" of a source may be expressed in terms of the values of intensity obtained when first the rays are passed through a solution, which only allows rays of a wave-length of 0.582μ to pass, and secondly, through a red glass only allowing rays in the neighborhood of 0.657μ to be transmitted.

[5] The intensities of two sources of light, which differ in composition, cannot be rigidly compared with and expressed in terms of a standard from which they differ. An estimate of their relative intensities can be made, however, by comparing them in the neighborhood of 0.582μ, which can be accomplished by causing the rays to be transmitted through an appropriate solution or colored glass.

the other hand, a high percentage of radiation in the blue and violet regions of the spectrum causes illuminated objects to appear brighter and enables colors to be distinguished better, but these highly refrangible rays do not greatly contribute towards the assistance of acuteness of vision.

Finally there is the question of the distribution of light in the workshop to be considered. If the sources of light are directly visible, this fact tends to fatigue the eyes, owing to the accidental production of bright retinal images. Even if these sources are not directly gazed at, the mere fact that they are within the range of vision causes the pupil to contract, with the result that the general surroundings appear to the eye as if less brightly illuminated than they actually are.

Then, whenever the illumination seems insufficient, the workman is compelled to bring his eyes near to the work, and the tendency to visual fatigue following near accommodation is intensified. Fatigue of this nature is liable to lead to progressive myopia; in the case of long-sighted people it is particularly liable to cause headache and other troubles. We have not troubled to consider the corresponding case in which the actual or relative illumination of the workshop is high enough to be inconvenient, this being a state of affairs which is not met with under ordinary practical conditions.

This question of the effect of illumination upon the organs of sight is important, especially in the case of those whose eyes are very sensitive. But habitually working under artificial illumination is apt to lead to other grave troubles. In workshops so lighted the general hygienic conditions are usually more or less unsatisfactory. In cases in which natural illumination is employed by day, and we only have recourse to artificial lighting by night, the premises will probably not become unhealthy in themselves, but yet habitual working in the night-time is open to well-known objections from the hygienic and social point of view. But the existence of workshops which are illuminated solely by artificial means is yet more to be deplored. The danger of insanitary and unhealthy conditions arising in circumstances in which the microbe-destroying action of the sun's rays is not available need hardly be insisted upon. Such conditions are known to be particularly favorable to the development and propagation of tuberculosis.

Premises which are used continuously at all hours, and from which the sunlight is always excluded, are also liable to suffer as regards ventilation. Such vitiation of the air is the more to be feared, because, except in the case of electricity, the illuminants themselves help to use up the available air and add their products of combustion to an atmosphere which already suffers from the respiratory products of the inmates.

The evil of artificial lighting is partially limited by the fact that it is expensive. Moreover, work is never so well or so rapidly done by the aid of lamps as by daylight. It is certain, therefore, that manufacturers only have recourse to artificial light when they are compelled to. The State is hardly in a position to forbid the carrying out of work under these circumstances, but even if working by night be regarded as inevitable, however, special reservations may be made in the case of women and children.

Rooms from which the rays of the sun are always excluded are usually of

a very special nature, such as vaults for the storage of wine or beer, refrigeratory apartments, etc.; there are also workshops in the basements or at the back of buildings, chiefly situated in the center of Paris. Premises of the first class are not very numerous. As regards the underground or back workshops referred to, it may be pointed out that land in the centre of Paris is so dear, and the demands of business so exacting in this region, that it would be impossible to forbid their use altogether without greatly injuring a considerable number of important vested interests. All that can be done at the present time is to insist upon such premises being as well ventilated and lighted as possible. The severity of regulations affecting the lighting and general conditions prevalent in such workshops would in itself tend to discourage their too rapid growth, and would possibly reduce the number already in existence.

Before concluding it may be well to throw a glance over the legislation in other countries affecting this matter.

In Belgium the wording of the royal decree of March 30, 1905, relating to the health and safety of workers in industrial undertakings, as specified in the law of December 24, 1903, is as follows :

"Art. 6. Workrooms shall be suitably illuminated. During the day they must receive adequate daylight illumination. In all cases artificial illumination is admissible, if, owing to the position of neighboring buildings or on account of other industrial conditions, the rooms do not receive the degree of illumination which the work carried out demands."

In addition these regulations contain the following specifications regarding artificial illumination :

"Art. 7. The artificial lighting shall provide a constant and sufficient degree of illumination. Suitable measures must be taken to ensure that the means of illumination do not unduly heat or vitiate the air in the premises.

"Art. 9. Workmen must be protected against excessive radiation from the illuminating apparatus."

In Holland the royal decree of January 31, 1897, relating to the conditions of working of female and young employees under unhealthy or dangerous conditions does not allow the person protected to be employed on premises where, between 9 in the morning and 3 in the afternoon, artificial means have to be resorted to in order to secure sufficient illumination (save only in exceptional cases when the condition of the atmosphere renders artificial light essential). Moreover, the intensity of illumination must conform with certain definite requirements. In the case of the following trades—embroidery, working in precious stones, gold, and silver, engraving metals or wood, the manufacture of instruments, printing, mechanical knitting and quilting, sewing, draughtsmanship, the repairing of clocks and watches—an intensity of at least fifteen bougie-meters is prescribed. In the case of other works requiring good lighting, an intensity of ten bougie-meters is necessary.

In Austria the regulations of the Minister of Commerce, dated November 23, 1905, and applying to industrial licensed premises, contains the following passage, under the title 'Natural and Artificial Illumination' :

"12. The windows and skylights in workshops and factories must be so designed as to be adequately illuminated for the purposes of facilitating the work executed by the light they furnish. Measures must, however, be taken to secure that workers are not subjected to the direct rays of the sun in confined places.

"13. All factories....must be adequately lighted during the day."

In Germany, in the special case of printing works and factories for the casting of type, we observe, in the regulations prescribed on July, 31, 1897, the following remarks:

"1. The floor of such factories must not be less than 1 meter below the ground-level. Exceptions may, however, be authorized by the authorities, provided special appropriate provision is made for hygienic ventilation and lighting....

"3. ....The rooms must be furnished with windows in sufficient number and of sufficient area in order to illuminate the premises satisfactorily....

"12. Illuminating apparatus capable of giving rise to production of a considerable amount of heat must be provided with means of protection in such a way as to avoid excessive heating of the workshop."

In Switzerland the regulations issued by the Federal Council in December 13, 1897, contain the following directions as to the rebuilding of factories....

"C. The windows shall be at least 1.80 m. in height and their distance from the ceiling shall not exceed 30 centimeters.

"D. Workshops....must be provided throughout with satisfactory natural and artificial illumination."

In the Grand Duchy of Luxemburg the regulations are as follows: (Grand Ducal Decree of March 11, 1904, with reference to the security and health of workers in industrial factories and offices, Art. 6): "Premises wherein work is carried out must be provided with suitable natural illumination by day and with proper artificial illumination by night. The artificial means of lighting must be such as to enable a suitable order of illumination to be secured."

Finally, we may quote the law of January 16, 1904, in Western Australia, which is as follows:

The inspector may, at the desire of the authorities, or at the request of the occupant of a factory or workshop, etc., prescribe what space of cubic or superficial feet shall be reserved for the use of each person working therein....The space so to be reserved shall not be deemed to be reserved unless it is kept properly lighted, etc."

Compared with the various regulations on the part of foreign nations, the French regulations of November 29, 1904, appear to fill an intermediate position in the scale of severity.

Without doubt this prescription is a little vague, but it is not possible to frame anything more definite without insisting upon too rigorous regulations such as are not adapted to the flexible and variable modern industrial conditions and would certainly be excessive in many cases.

The Administration can, therefore, only specify details in this matter by way of recommendation. In this way it may be suggested that walls of

workshops should be painted a light color so as to avoid absorption of light and facilitate diffusion.

In cases in which the illumination is furnished by one or more sources of light of high temperature (such as the electric arclight, it is desirable that the tint of the walls should verge upon the yellow, in order to reduce the proportion of highly refrangible rays in the light utilized. The direct rays from the arc should never be received by the eye; an excellent method of illumination is to project the light from the arc on to a white ceiling, at the same time screening it in a downward direction; in this way the available illumination is provided by the light transmitted through the screen reinforced by that reflected from the ceiling. As a matter of general principle, sources of light, especially those of intense brilliancy, should invariably be placed outside the field of vision of the workers.

But however high the value of these recommendations is felt to be, it appears undesirable to give them the form of definite legal regulations. In this report it is only desired to express the entire approval of the Administration as to the regulations specified in Article 5 of the Regulations of November 29, 1904.

The question of industrial lighting has again been taken up by the French government, which has appointed a special commission to investigate and report. The official announcement, as translated by the *Illuminating Engineer,* London, is as follows:

At the instigation of the French Minister of the Interior a Technical Committee has been appointed to deal with natural and artificial illumination, and having for its main objects—

1. To study, from the standpoint of general health and its effects upon vision, the various methods of artificial lighting now in use.

2. To determine the composition and quality from a hygienic standpoint of the different combustible illuminants, and to examine the effect of prejudicial gases and the amount of heat developed thereby.

3. To fix a certain minimum amount of artificial illumination favorable to the normal requirements of vision.

4. To study the most practical methods of measuring illumination.

5. To formulate recommendations governing the best means of applying customary methods of lighting to the chief varieties of industrial operations.

6. To present to the Ministry a report on the subject of short sight and impairments of vision and on the best methods of guarding against the causes of myopia.

This committee is to present a summary of its work to the Ministry of the Interior every three months, and at the end of the year to present a final report embodying its conclusions.

The carrying out of this project will be the charge of the Directeur de l'Assistance et de l'Hygiène Publiques. The Committee is of a most representative character. It includes among its members medical men in practise, professors of physics and ophthalmology, representatives of gas and electric

lighting, inspectors of factories and workshops, etc., and should, therefore, act as a most valuable center for impartial information of hygienic aspects of lighting. The progress of the work of this Committee will be watched with great interest by all in this country concerned with illuminating engineering.

A PRACTICAL ILLUMINOMETER ESSENTIAL TO SPECIFIC LEGISLATIVE REQUIREMENTS.

The one weakness of all legislation on the subject of illumination thus far is its lack of definiteness. The only requisite to the removal of this fault is a practical illuminometer. By this will be understood an instrument possessing the following qualities:

(1) Absolute portability. It must be as easily carried as the larger sizes of photographic cameras of the kodak order.

(2) An accuracy in the hands of a non-technical and inexperienced user of not less than 10 per cent.

(3) Moderate cost. It should not exceed $50.00.

There is no reason why an instrument fulfilling all these conditions should not be produced; in fact, the illuminometer brought out within the year by Dow and Mackinney in England, comes so near meeting the conditions that it only needs to be Americanized to be fully up to the requirements. The only thing it lacks is a cheap and reliable current indicator. Such an instrument need not read in units, but simply indicate a constant potential or current strength. With this, and three or four ordinary dry cells, a standard light of great accuracy is obtained; and there is no reason why measurements of surface brightness or intensity of illumination should not be made by the ordinary observer with an accuracy of from 2 to 10 per cent., probably nearer the former figure.

With such an instrument available the conditions of illumination can be accurately specified in the labor or factory laws. In fact, illumination is susceptible of much more accurate definition than ventilation. As the perfection of the necessary instrument is unquestionably near at hand, and as there are several active agencies ready to promote legislation as fast as conditions will justify, it is safe to assume that lighting in the industries, including the employment of clerical labor, and in public institutions, will be specified by law in the not distant future.

REGULATION OF INDUSTRIAL LIGHTING BY ORGANIZED LABOR.

Not less important than the agitation of legislation on this subject is the interest which organized labor is beginning to take in questions of industrial hygiene. Some two years ago there was a general strike in the suit, cloak and skirt industry in New York City, which resulted in a substantial victory for the operatives. Among the original demands was one for better sanitary conditions in the shops. In the settlement it was agreed between the employers and employees that a board of sanitary control should be appointed, which should have authority to prescribe a code of regulations affecting factory sanitation. This board secured the advice of a number of specialists in the several branches of sanitation, including an illuminating engineer. An inspection was made of every factory or shop which could be found on Manhattan Island, numbering something over twelve hundred. As a result of this investigation, and the advice of experts, a code of regulations was issued which contains the following provisions with reference to lighting:

Halls and stairways leading from shops to be adequately lighted by natural or artificial light.

Sufficient window space to be provided for each shop, so that all parts of the shop to be well lighted during the hours from 9 a. m. to 4 p. m.

Where gas illumination is used, arc lights or incandescent mantles should be used.

All lights to be well shaded, to be placed above operatives, and not too near them.

During the past winter one shop was adjudged to be unsanitary to such an extent as to justify the union in calling out the operatives, as a result of which the proprietor was obliged to find other and better quarters.

The effectiveness of this method of controlling the physical conditions of labor is sufficiently apparent. Organized labor, generally speaking, will win where it is backed by public opinion, and in all measures looking toward the safe-guarding of health and life there will be no question as to their securing public approval.

DISCUSSION.

Chairman (Dr. H. E. Ives):—I am sure we all appreciate the vast importance of the publicity phase of any subject in which we are interested. At the close of his talk Mr. Elliott

has expressed an opinion as to how much a society which is made up of professional men can get into this publicity work. He has given it as his opinion that this is a society of illuminating engineers which cannot do any publicity work without having its motive questioned. I think some of us look upon the society as an illuminating engineering society, which can properly do work of the sort under discussion. Perhaps there are members present who would like to express some opinion on this point in discussing the paper.

Mr. E. C. Crittenden:—In this paper there is one point that strikes me from the point of view of the standardizing laboratory, and that is some of the expressions regarding the measurements of illumination. It is highly desirable that people who have to do with such movements as Mr. Elliott outlines should know that measurements can be made of illumination and made fairly reliable; but it is not a good thing to give the impression that any inexperienced and non-technical user can obtain an accuracy of less than ten per cent. with any instrument that he can carry around in his pocket. Referring to the Sharp-Millar illuminometer, I think that it is a highly useful instrument, but I believe those who have used it largely would not want to say they get with it an accuracy better than that which has been predicted for the very simple instrument proposed. We have felt at least in the work we have had to do that if we had to swear to results closer than five per cent. we would be in danger of committing perjury. I don't believe that any factory inspector of considerable experience can go into a factory and make measurements of illumination with an accuracy of two per cent., especially if there is any difference in color between the illumination and the standard in the photometer. However, that is not depreciating the Sharp-Millar photometer, but rather calling attention to the fact that any such photometer in the hands of an inexperienced observer could not be relied upon to give highly accurate results, and that the experienced observer must use extreme caution.

We have had a great deal of discussion which calls attention also to the fact that the mere measurement of intensity on the

working plane may not mean very much; so it seems to me in such work rather than to try to get instruments with which inexperienced observers can make observations it would be far better to turn our efforts toward having inspections made by experienced men who can judge the results obtained, instead of recording merely that the illumination is so many foot-candles.

No one will question the desirability of taking some steps for the conservation of the eyesight of workers, but it appears very doubtful whether any legislative requirements can be made definite enough to be effective. An appeal to the public spirit and humanity of employers may accomplish something, and as Mr. Elliott has said, organized labor can do much to force amelioration of extremely bad conditions; but I believe most effective work can be done by attacking the question from another side. Most employers must of necessity consider the matter on a basis of dollars and cents, and we should take full advantage of the fact that good lighting pays. If this society or the Association for the Conservation of Vision or any other agency can convince employers in general that money invested in good lighting is returned many fold in increased output and better work, as we have good reason to believe it is, we shall have gone a long way toward securing ideal lighting of workshops.

Mr. A. J. Marshall:—I think Mr. Elliott's idea, at least as I get it, is that instead of an inspector relying purely upon the judgment of his eye, to determine degrees of brightness, that he avail himself of a portable instrument which would make his readings more nearly accurate. Assuming that these inspectors are inexperienced at the start, and therefore unable to determine within a few per cent. illumination values, we at least can respect their general findings, and if they appear to vary widely one way or the other a more refined reading may be made by an expert. I think, however, that it will be found that as the inspectors become acquainted with the instrument, their ability will naturally increase, so that before long, even with more or less crude illuminometers, they will get quite reasonable results. In any event, it is probable that a good durable illuminometer would be preferable to the human eye.

Mr. G. H. Stickney:—This paper brings up an important branch of work in which it seems to me the Illuminating Engineering Society can contribute to advantage. That legislation is needed in connection with the regulation of illumination is self-evident. It must also be evident that such legislation will come sooner or later. One of the dangers which we now face is that some of the legislation may come too suddenly, so that it may be ill-advised and not productive of as good results as might be obtained with mature consideration. The laws now existing with regard to light and illumination, especially as applied to candle-power, are many of them based upon misconception and are therefore ineffective or harmful. For instance, I had occasion about two years ago to make an investigation into the laws of various states applying to locomotive headlights. In reviewing the few laws existing on the subject, I found nowhere a clear and definite statement regulating the intensity. In a number of states there were laws to the effect that headlights should have a power of 2,000 candles. Now, what does this mean? Does it mean that the lamp, without reflector, should give 2,000 candle-power, or that the intensity of the beam should be 2,000 candle-power? I presume that the former was intended, although the latter would be implied from the wording. When one considers that a beam of 5,000 to 6,000 apparent candle-power is obtained at 100 feet from a 15-watt tungsten lamp in an automobile headlight reflector, the indefiniteness of the legal specification and the chance that it will fail in its purpose are readily evident.

It seems to me that the society could do something toward guiding legislation to the end that we may have wise and definite laws, and also, by coöperation with the American Society for the Conservation of Vision and through such other channels as may seem best, to disseminate knowledge and create a public opinion which will guard against such contingencies.

Dr. Winthrop Talbot:—It has been my privilege to come directly here from the Conservation Congress in Kansas City where the major part of the session was given over to a consideration of human conservation. An effort is being made to-day to bring

about on the part of employers of labor, that is say through the national associations of manufacturers in different lines, the establishment of committees on human conservation to deal with all problems relating to human comfort and human efficiency. That this movement will be thoroughly organized during this coming year, is probable. Legislation, I feel, should not be too far in advance of the popular education on the matter legislated about. In addressing the state inspectors of factories of Ohio last winter it was a matter of greatest interest to me to find that the personnel of that body was of a very high order; that is to say, the men, and the women too, were deeply and sincerely interested in bringing about better conditions. Therefore, it seems to me that at the present time one is justified in advocating legislation which shall be directive and educative in character. It would seem as though any factory inspector might be required by law to report whether in his judgment the illumination in any particular industry was sufficient and satisfactory. His judgment could then be verified by further examination. I have been greatly impressed in inspecting factories where electric lamps are made to find that there the methods of illumination are oftentimes open to severe comment. I believe we should rectify the faults which lie near us before criticising others. One of the main points of criticism I would make about the efficiency in the lamp making industry is that there is oftentimes too much light, too much illumination. There has been a number of cases where eyes have been hurt through too much illumination. Therefore, the amount of illumination in any given industry, I believe, must be determined carefully by the particular needs in the particular operation for which light is to be provided. I doubt whether we can go further into legislation pertaining to industrial conditions to-day than for the inspector to report whether the illumination is satisfactory or not satisfactory, and that he be given authority to require changes to be made. Legislation on this subject should be advocated I believe to this extent at least.

Dr. M. G. Lloyd:—There is one aspect of legislation for which I think the time is ripe and which should be a very simple proposition, and that is in regard to the glare of auto-

mobile headlights. The subject is one on which there seems to be enough general opinion so that it is unnecessary to argue for it. Some municipalities have adopted ordinances covering this point, but I have failed to notice that they have been enforced very rigidly. It seems to me that this is a thing the members of this society might advocate in their own districts, and I trust that those who drive automobiles, and no doubt there are many of them in the society, will make it a point of setting an example in their own neighborhoods by keeping their headlights directed below the horizontal.

Mr. J. R. Cravath:—There is no doubt that we will have legislation some day and that we ought to have it, but there are many points undecided at the present time. If I were asked to formulate anything more than the simplest laws I should not dare undertake the task. This is a problem we should be thinking about.

Mr. E. L. Elliott (in reply):—As to the accuracy of measurement, what I say of inexperienced and non-technical observers needs to be qualified. In the actual working out of any factory law in which there is measurement of illumination it is a matter of course that the inspector will soon become familiar with his instrument. Secondly, I think it is the experience of those using and comparing results of illuminometers that while there is considerable error between different individuals, the errors of measurements of the same observer are not large, especially after he gets the hang of his instrument. It would be a necessity if any great accuracy were required for the different inspectors to calibrate themselves if they wanted to check results one against another; but I dare say that one inspector after a week's work would bring his own readings of the instrument within reasonable precision, say to within five or ten per cent.; then by calibrating the different observers their results could be compared. I know that even in the case of the mercury-vapor light in comparing my own readings with those of another inexperienced observer, that by agreeing upon our methods of observation we soon were able to get exceedingly concordant results.

As to the employer's interest in legislation, that of course

must not be left out of the question. In the Joint Board of Sanitary Control regulations, which I must confess to having had a part in, I dwelt upon the fact in my report that it was most important to the manufacturer to make all the regulations required to protect the operator, and that it would be a benefit to the manufacturer in increasing the efficiency of his labor; therefore, there need be no hesitation, so far as the manufacturer was concerned to comply with the regulations. The question was brought up by Mr. Williams, Labor Commissioner of New York State, as to what effect it would have upon the manufacturers. I made the same point, that the legislation would not be burdensome, provided of course that the regulations were reasonable.

As to specifying what kind of illumination, Mr. Cravath, and perhaps others, would hesitate. There is an adage about certain individuals being willing to rush in where angels fear to tread. I confess I am ready to rush in. I am willing to specify that in storage rooms and passageways and alley-ways that the illumination shall not be less than a thousandth of a foot-candle. I don't think I would be taking any risk if I specified that in a low passageway of a store room where workmen were obliged to move about carefully that the illumination should not be less than a quarter of a foot-candle in intensity. I believe that it is possible to specify the minimum illumination or the approximate illumination required for most any kind of work so as to prevent abuses; and the prevention of abuses is about the most we can hope for in such kind of legislation.

Now, then the relation between light and industrial accidents is a very important one. I didn't bring it out in this paper. There was a most convincing paper on that subject given by Mr. Calder before the American Society of Mechanical Engineers last winter in which he showed by a curve and table the proportion of accidents in the different months, starting with June, reaching its maximum in December, and then running right down to the next June again. There is only one conclusion to draw from it, that industrial accidents occur in dark months, and if industrial accidents occur in dark months they are due to a lack of proper illumination. Industrial accidents, if they are due to bad illumination, can certainly be largely reduced by requiring certain minimum illumination in different cases.

As to the suggestion made by our chairman that there might be a difference of opinion as to whether the Illuminating Engineering Society might advocate certain legislation, that is a question; but I believe that our society has got to be one of two things, it has got to be an engineering society or a social organization.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VI. NOVEMBER, 1911. NO. 8

COUNCIL NOTES.

The November meeting of the council was held on the 10th instant in the general office of the society, 28 West Thirty-ninth Street, New York. Dr. A. E. Kennelly, president; V. R. Lansingh, treasurer; L. B. Marks, E. B. Rosa and P. S. Millar, general secretary, were present.

After the adoption of the minutes of the October meeting, monthly reports were received from the general secretary and the chairman of the finance committee, Mr. L. B. Marks.

Authorization was given to Mr. Marks to engage a certified public accountant to audit the books of the society for the year ending December 31, 1911.

The following proposal to amend section 7, article 4, of the by-laws received an initial reading:

Omit the phrase "by a public auditor" in the present by-law which reads as follows:

> Article 4. Section 7.—The accounts of the secretary and treasurer, shall be audited annually just prior to the annual meeting by a public auditor.

The executive committee reported that it had accorded authorization to either the sub-committee or the committee on nomenclature and standards to proceed with the work of enlisting international cooperation on the subject of photometric units and nomenclature in accordance with the action taken by the Baltimore convention (1910) and the proposal of the sub-committee as set forth in its progress report presented at the Chicago convention (1911). The executive committee asked the approval of the council on this act. In granting such approval the council adopted the following resolution:

> *Resolved*, That the committee on nomenclature and standards be instructed to communicate with bodies throughout the world, interested in photometry and illumination, with a view to arranging an international conference

to consider the definition of terms employed in illuminating engineering, their nomenclature and notation.

In conjunction with the acceptance of the final report of the 1911 convention committee, the following resolution was adopted:

Resolved, That the council of the Illuminating Engineering Society take this opportunity to express its high appreciation, as well as the society's thanks, to the general convention committee and to the various sub-committees for their splendid work which in so large part contributed to the success of the Chicago annual convention.

Mr. Marks reported on several phases of the work of preparing a primer on illumination which is being compiled by the committee on illumination of which he is chairman. The topics introduced by Mr. Marks were discussed by the council.

From the board of nominations the following list of nominations, which is to be presented to the membership at the forthcoming election, was received:

1912.

For president, V. R. Lansingh.

For vice-president (from N. Y. section), Norman Macbeth.

For general secretary, Preston S. Millar.

For treasurer, W. J. Serrill.

For directors, C. J. Russell, A. J. Marshall, R. C. Ware.

Thirteen applicants were elected. Two resignations were accepted; and the name of one deceased member was dropped from the roll of the society.

SECTION MEETINGS.

CHICAGO SECTION.

Messrs. F. A. Vaughn and G. H. Cook presented at the November meeting of the Chicago section on the 16th instant a commendable paper entitled "Theatre Illumination." The paper dealt with the divers problems encountered in lighting theatres effectively. The paper with its attending discussion will appear in December of the TRANSACTIONS.

Final arrangements for the December meeting on the 21st ultimo have not yet been announced; but the meeting in all probability be devoted to a discussion of a paper entitled "School Room Illumination" by Mr. H. B. Wheeler.

NEW YORK SECTION.

The New York section held a meeting November 9th in the United Engineering Societies' Building. Mr. F. G. Hancock of the General Electric Company read a paper on "Publicity Work in Illuminating Engineering."

At the meeting which will be held December 14th, Dr. Ellice M. Alger of New York will read a paper on "Conservation of Vision." An unusually large attendance at the meeting is expected. Invitations have been issued to a number of prominent opthalmologists, physiologists and representatives of other correlated societies throughout the East to participate in the discussion of the paper.

PHILADELPHIA SECTION.

Two papers were presented at the meeting of the Philadelphia section November 17, one "Natural Gas, Its Production and Utilization" by M. George S. Barrows, and the other "The Application of Photometric Data to Interior Illumination" by Mr. E. J. Brady. There was also an exhibition of some of the latest developments in gas lamps and gas mantles. Sixty-six visitors and 122 members were present.

The next meeting will be held December 15th.

NEW ENGLAND SECTION.

The January meeting of the New England section will probably be held on the 8th. The program for it has not yet been announced.

NOTICE.

Members of the Illuminating Engineering Society who wish to discuss papers on certain phases of illuminating engineering in which they are especially interested should send their names accompanied by a list of the particular subjects to the general office, 29 West Thirty-ninth Street, New York. As papers on those subjects become available advance proofs of them will be sent to the members and others whose names are on file. It is believed that this scheme will stimulate much timely and valuable discussion on all the papers read before the society, and consequently increase the value of the TRANSACTIONS.

THE EVALUATION OF LAMP LIFE.*

BY P. S. MILLAR AND L. J. LEWINSON.

In the early days of electric lighting the attention of those concerned in the manufacture and operation of incandescent lamps was devoted largely to the simple problem of making lamps burn. As lamp manufacturing improved and experience in the operation of electric lighting plants became more general, the complex technical problems of lamp operation received attention. It became recognized that with increased hours of burning, lamp bulbs blackened and candle-power declined. Finally it was pointed out that in the course of lamp operation there comes a time when the lamp is so dim that it is desirable for economic and other reasons, to throw it away and replace it with a new lamp.[1]

During the period 1887 to 1892 the electrotechnical press and the Transactions of the American Institute of Electrical Engineers, the Association of Edison Illuminating Companies, and the National Electric Light Association, contained a number of articles and recorded discussions in which the suggestion appeared that the most economic efficiency for incandescent lamps may be computed from data on cost of current, cost of lamp and watts per candle throughout life. The general purport of such discussions was that central stations should improve pressure regulation, after which the use of higher efficiency lamps would become desirable.

In 1892 O'Keenan[2] applied to published life test data upon European incandescent lamps a method of computing the expiration of the useful life of the lamp, considering rate for energy, price of lamp, and performance of lamp throughout life, and arrived at what he called the "smashing point," (*point de cassage*) or end of useful life of the lamp.

Hering[3] reviewed O'Keenan's article and endorsed his method,

* A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911,

[1] For one of the earliest, if not the earliest, published suggestions to this effect, see C. E. Weber, *Journal of the London Society of Arts*, vol. 35, p. 56.

[2] *L'Industrie Electrique*, Nov. 25, 1902.

[3] *Electrical World*, 1892, p. 404.

emphasizing the importance of such considerations as O'Keenan had advanced. Later[4] he applied the method to results of life tests made by Prof. Thomas upon American incandescent lamps of various makes. At this time it may be interesting to note that Hering's calculations, based upon energy at 15 cents per kilowatt-hour and a 45-cent lamp whose initial watts-per-candle was 4.2, led to the conclusion that the useful life of the lamp was about 400 hours at the expiration of which time the candle-power was 78 per cent. of the initial and the watts-per-candle was 5.3.

From that time the idea of useful life for incandescent lamps became more prominent in the minds of those who had to consider lamp life. Thomas[5] noted that when lamps deteriorate materially they should be discarded. As being suggestive in that connection he showed for 16 candle-power lamps the life until the candle-power had depreciated to 14, a decline of about 12.5 per cent.

Feldman,[6] after pointing out that lamps depreciate in candle-power as they burn, showed for certain lamps the hours life to 50 per cent. of the initial candle-power. Gasnier[7] discussed decrease in candle-power and efficiency in incandescent lamps with hours of burning. Upon the consideration that 20 per cent. is about the smallest noticeable difference in illumination, he concluded that lamps should be permitted to fall slightly below 80 per cent. of initial candle-power before being replaced and suggested 75 per cent. as a reasonable limiting value.

Nearly all study of lamp performance in the early nineties was confined to manufacturers' laboratories. At first the usual factory tests determined only the burning hours. Later the rate of candle-power change was determined in special tests. One lamp manufacturer stated that in 1890 candle-power measurements were introduced as a part of the testing routine in his laboratory. His records show the first application of the 80 per cent. criterion to have been made in February, 1896. When in November, 1896, the Electrical Testing Laboratories, then the Lamp Testing Bureau, undertook lamp testing, the demand was for "hours life to 80 per cent. of initial candle-power or to

[4] *Transactions A. I. E. E.*, 1893.
[5] *Transactions A. I. E. E.* June 7, 1902.
[6] *Electrician*, p. [illegible] Nov. 25, [illegible]
[7] *L'Industrie Électrique* July 25, [illegible]

earlier failure." It is probable therefore that 20 per cent. candle-power decline as a measure of useful life for testing purposes was adopted by some lamp manufacturers and was first applied extensively in commercial practice by the lamp committee of the Association of Edison Illuminating Companies. From this beginning it has grown to its present influential position as a criterion in lamp testing.

In industrial lighting practise the 80 per cent. criterion has made some impression. A few central station companies who make a special effort to furnish a superior lighting service encourage removal of old lamps from their circuits and even effect such removal by their own efforts. Lamps removed from circuits in this way in the practise of these companies are tested and all below some given percentage of initial candle-power are discarded. This percentage is usually fixed conservatively high in order to keep the lamps in service well above the 80 per cent. point so far as may be practicable.

In lamp testing work, the 80 per cent. criterion prevails largely. In this country practically all specifications for carbon and Gem filament lamps employ this basis of evaluation of lamp life, and in much of the practise it is gaining consideration in tests of tungsten filament lamps, although it has little official standing as yet in that connection. It is understood that abroad the 80 per cent. criterion is used quite extensively in lamp testing work.

When first employed as a life testing measure, the 80 per cent. criterion served a most useful purpose in pointing to the ineffectiveness of long hours of burning involving low candle-power and efficiency, a lesson which needed to be taught in those days even more than to-day. Subsequently it has served an excellent purpose in continuing to emphasize the importance of good candle-power maintenance and in discouraging the somewhat natural tendency to judge lamp life by total hours of burning.[8]

MINOR DISADVANTAGES OF 80 PER CENT. CRITERION.

In testing lamps under the conventional specifications which call for a determination of "life to 80 per cent. candle-power

[8] Incidentally, the authors deplore the present-day tendency of lamp manufacturers to return to a total life basis in lamp specifications.

or earlier failure," inaccuracies have been encountered due to difficulty in determining precisely the hours corresponding to a 20 per cent. candle-power depreciation. In such work it is customary to determine the candle-power of a lamp at intervals and by plotting a curve through the points so determined, to ascertain the time when the candle-power curve crosses the 80 per cent. candle-power line. Photometric errors of one or two per cent., quite likely to be encountered in commercial work, may lead to inaccuracies in the "80 per cent. life" of as much as five or ten per cent.

Among other minor disadvantages, the method attributes no value to the service of the lamp after it has depreciated in candle-power more than 20 per cent., notwithstanding that in some classes of service this portion of the lamp's life, though less efficient, has some value. The small disadvantage so incurred is more than compensated for by the premium which the practise places upon the desirable earlier performance. In fact if insistence is to be placed upon candle-power maintenance, some later and less effective portion of the total life of most kinds of lamps must be thrown away.

Another disadvantage under which the method sometimes labors is the neglect of the candle-power maintenance element when candle-hours are not figured and when reliance is placed upon the life factor alone. Referring to fig. 1 which illustrates the performance of a normal lamp of a certain type and the performance of a lamp which "slumps" in candle-power, it will be noted that the two candle-power curves intercept the 80 per cent. candle-power line simultaneously and would be given equal value if the candle-hours were not computed. When the candle-hours are computed, the proper relative values are assigned, the lamp which slumps being credited with (1500 × 0.838 =) 1419 candle-hours and the normal lamp with (1500 × 0.933 =) 1 467 candle-hours.

In passing it may be noted that the candle-hour method has been employed very largely in this country. Those having to do with the evaluation of lamp performance have usually been keenly alive to the danger of relying solely upon the useful life figure. In fact a few years ago the candle-power maintenance element was considered so important that some attention was

given to a proposal to evaluate the useful life of lamps in terms of a value arrived at by multiplying the hours useful life by the average excess of candle-power over 80 per cent. of initial; that is to say, the hours useful life multiplied by the difference between the mean candle-power throughout such

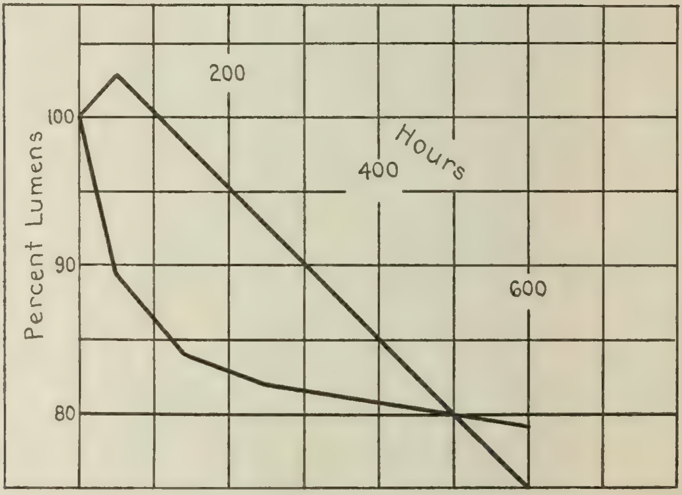


Fig. 1.—Performance of lamps illustrating need for computing candle-hours

life and the 80 per cent. candle-power value. Needless to say this proposal was too radical and gave too large a relative value to the candle-power maintenance element.

CHIEF DISADVANTAGE OF 80 PER CENT. CRITERION.

The conventional method hitherto employed of evaluating lamp life notwithstanding its liability to inaccuracies and other minor disadvantages would afford an acceptable criterion for lamp testing purposes were it not that it assigns exaggerated importance to elements believed to be of lesser value, as a result of which other more important elements fail to receive due recognition. The method of evaluation proposed in the latter part of this paper represents an attempt to assign proper value to both important elements of performance. The improper valuation of the elements of candle-power maintenance and lamp failure is the subject of the illustrated discussion in the following paragraphs.

In introducing these illustrations it should be said that any system which takes account of only the light produced, while neglecting changes in energy consumption, is liable to error. In most of the following discussion the change in watts throughout life is neglected in order to rid the problem of one variable; but this should not be permitted to obscure the fact that the final and proper basis of comparison must take into consideration also the energy consumption.

For a similar reason the candle-hours are not shown in these illustrations. The fact that the candle-power maintenance differences are small in comparison with the large differences in the time element would seem to justify the omission of the candle-hours in the interests of simplicity.

ILLUSTRATIONS OF MISLEADING CHARACTER OF 80 PER CENT.

To select a simple illustration; it is considered that two groups

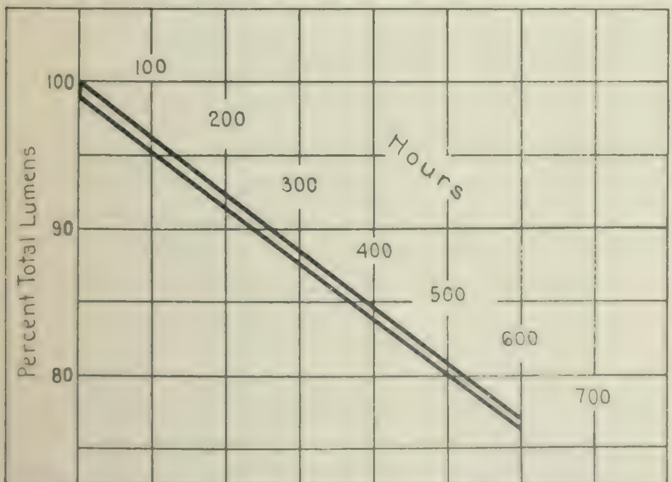


Fig. 2.—Total flux of two groups of lamps.

of 100 lamps each are placed within translucent glass fixtures and so employed illuminate two comparable rooms. All the lamps of these groups are considered to decline in candle-power similarly, and at the rate indicated by the upper diagonal line of fig. 2, which shows also the total light produced by the lamps of group 1 throughout a period of 600 hours. One lamp in group 2 fails as soon as the current is turned on. The total

light yielded by group 2 is therefore represented by the lower diagonal line of fig. 2. Bearing in mind that all the 199 lamps of the two groups perform similarly, declining in candle-power at the rate indicated by the upper diagonal line, it is evident that the lamps of group 2 are one per cent. inferior to the lamps of group 1. This inferiority is arrived at as a result of the consideration that there are 99 lamps in one group as compared with 100 lamps of equal value in the other group, or it is reached by considering the upper diagonal line to represent the average performance of the lamps of each group, and mul-

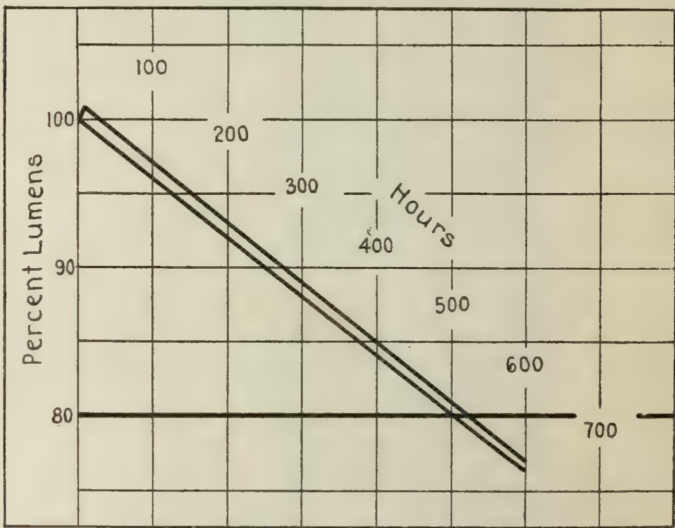


Fig. 3.—Performance of two lamps which differ in lumens by one per cent. throughout life.

tiplying such performance by 100 in the case of group 1 and by 99 in the case of group 2. If, however, these two curves of performance, representing respectively the total light produced by the two groups of lamps, be rated in accordance with the conventional method of determining the hours at which the candle-power curve crosses the 80 per cent. line, the result will be a useful life for the first group of 522 hours and for the second group 502 hours, a difference of four per cent. in the case of lamps which differ by one per cent.

A similar case is the performance of two lamps, illustrated in fig. 3. One lamp declines, as shown by the lower diagonal line,

while the other lamp first rises one per cent. in candle-power and then declines in such manner that throughout it yields one per cent. more light than its fellow. The difference in the values of these two lamps appears to be one per cent., yet according to the conventional method of rating "useful" life, this difference again is 4 per cent.

To supplement the two hypothetical illustrations just discussed, three other illustrations of the misleading character of the conventional method of evaluating useful life have been se-

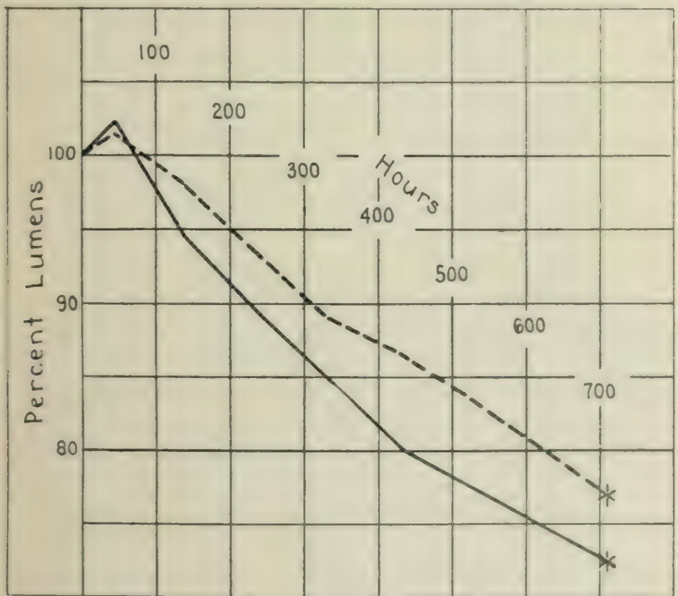


Fig. 4.—Performance of two lamps throughout life.

lected from the records of the Electrical Testing Laboratories, and are here presented with the assent of the lamp committee of the Association of Edison Illuminating Companies for whom the lamps were tested.

Fig. 4 illustrates the candle-power curves of two lamps which burned out simultaneously at 708 hours. Judging these lamps by the conventional method, lamp No. 47 has a useful life of 615 hours while lamp No. 79 has a useful life of 430 hours, giving a superiority of 43 per cent. for the former. The two lamps

burned for the same period and the only difference was that lamp No. 79 yielded less light than lamp No. 47, the difference attaining a maximum of about 8 per cent. There appears to be no reasonable ground for attributing a superiority of 43 per cent. to lamp No. 47.

Fig. 5 shows the performance of two lamps. According to the conventional method of arriving at "useful" life the superiority of the lamp represented by the broken line is ($738 \div 548 = 1.35$) 35 per cent. The real point of superiority lies in

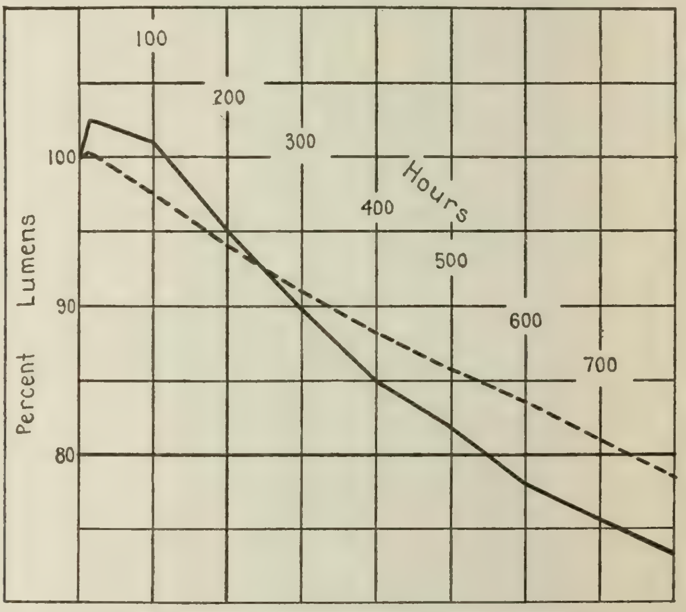


Fig. 5.—Performance of two lamps throughout life.

the greater candle-power of the lamp during the period subsequent to 250 hours. This difference attains a maximum of about 7 per cent.

Fig. 6 shows the performance of four lamps; No. 10,021 fails at 248 hours, No. 9,023 declines 20 per cent. in 746 hours. According to the conventional method, the mean "useful" life of these two lamps is $[(248 + 746) \div 2 =]497$ hours. The third curve represents the mean performance of lamps Nos. 8,021 and 12,011 which decline similarly and which are therefore represented by a single line. These lamps have the same

"useful" life as the mean of the two other lamps just referred to according to the conventional rating and are therefore considered to be their equivalent in value. The fact that lamp No. 9,023 yields about 10 per cent. more light throughout a period of 300 hours than do lamps Nos. 8,021 and 12,011, is sufficient in standard practise to counterbalance the fact that

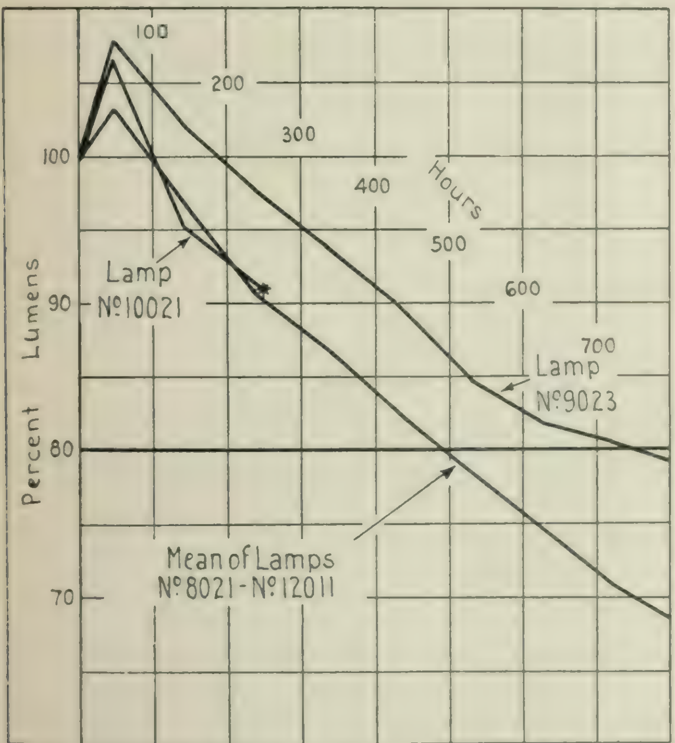


Fig. 6.—Performance of four lamps. (See fig. 10 also.)

lamp No. 10,021 has failed and gives no light. Such distortion of values is a common occurrence.

To supplement these illustrations drawn from test records, two assumed performance curves are presented for the purpose of mathematical analysis. Lamp No. 1 decreases in candle-power at some given rate, whereas, lamp No. 2, after increasing a certain percentage above No. 1 in the first few hours, decreases in candle-power, maintaining a constant per cent. candle-

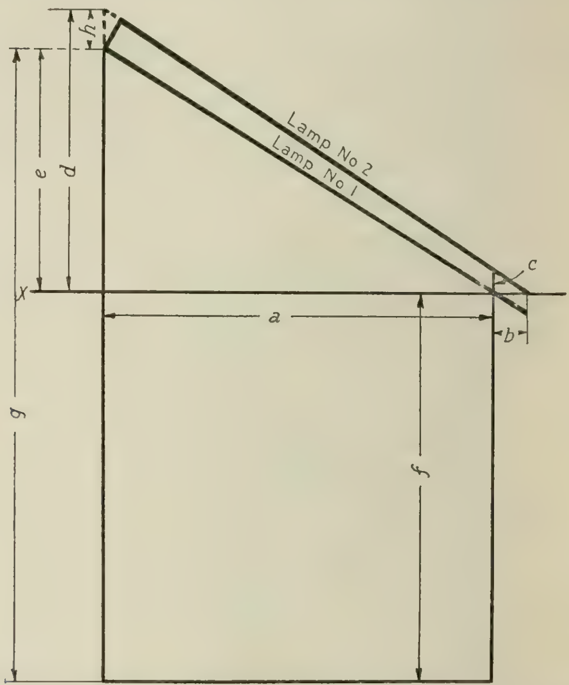


Fig. 7.—Mathematical representation of the performance of two lamps.

power above No. 1. This performance is illustrated in fig. 7, where—

g = initial candle-power = 100 per cent.

e = allowable drop in candle-power throughout "useful" life.

$f = (g - e)$ = limiting candle-power to which "useful" life is measured.

a = "useful" life of lamp No. 1.

$a + b$ = "useful" life of lamp No. 2.

c = difference in candle-power at the end of the "useful" life of the first lamp.

Continue curve No. 2 until it intersects the line of zero hours. By similar triangles,

$$\frac{b}{a + b} = \frac{c}{d}. \tag{1}$$

Solving for the ratio $\frac{b}{a}$

$$\frac{b}{a} = \frac{c}{a - c}. \tag{2}$$

Since the percentage difference in candle-power between curves Nos. 1 and 2 is considered constant,

$$\frac{h}{c} = \frac{g}{f},$$

whence

$$h = \frac{cg}{f}.$$

Now $d = e + h = e + \dfrac{cg}{f}$.

Substituting these values in equation (2) replacing f by its equivalent $g - e$, and simplifying we have the following:

$$\frac{b}{a} = \frac{c\,(g - e)}{e\,(g - e + c)} = \frac{c\,(100 - e)}{e\,(100 - e + c)}$$

It is evident from this equation that the increased effective life due to the higher candle-power maintenance of lamp No. 2 is dependent upon the difference in candle-power at the end of the "useful" life of the first lamp and the allowable drop in candle-power throughout "useful" life.

Assuming this latter to be 20 per cent., and that throughout curve No. 2 is 1 per cent. higher than curve No. 1 in candle-power value,

$$e = 20,$$
$$c = 0.8 \ (1\% \text{ of } 80),$$

whence

$$\frac{b}{a} = 0.0396,$$

which means that the increased life to 80 per cent. of lamp No. 2 over lamp No. 1 is 3.96 per cent. In this case a difference of 1 per cent. in candle-power maintenance means practically a 4 per cent. difference in "useful" life provided the life to 80 per cent. is considered. Had the life to 70 per cent. been chosen, this 1 per cent. difference would have meant an increase of 2.3 per cent.

These illustrations demonstate the fact which the authors seek to establish in this paper, that the 80 per cent. criterion, however reasonable and suitable as an indication of candle-power diminution which may be tolerated in practise, proves misleading

to a serious degree when applied strictly as a candle-power limit in determining relative values of lamps. In any practise which is based upon this method, conclusions are liable to error to the extent that they are influenced by such values. The truth of the matter is that the burning hours corresponding with a given candle-power depreciation do not afford a measure of useful life.

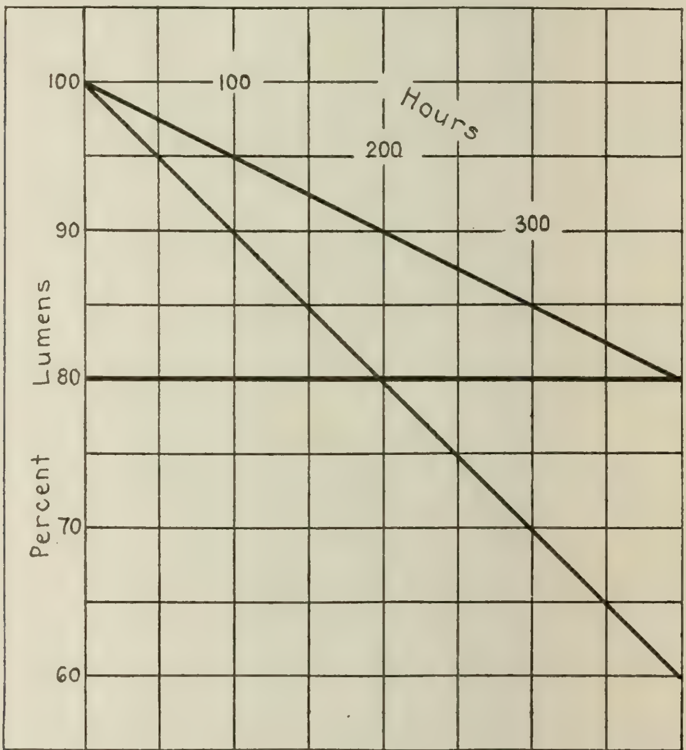


Fig. 8.—Illustrating "useful" life as a measure of flux decline.

They constitute merely a measure of the net rate of candle-power depreciation throughout a given period. They represent values, which, generally speaking, vary inversely as such net rate of decline. The character of this effect is made clear in fig. 8, where two lines of decline in candle-power are shown. In one the rate of decline is twice that of the other. In consequence thereof, the "useful" life value of the one is half that of the other.

WHAT CONSTITUTES MERIT.

With the objectionable feature of the conventional method clearly established, it is profitable to consider what constitutes merit in an illuminant. There are certain fundamental qualities such as steadiness and color with which the ordinary life test is not concerned. These aside, the measure of merit of an illuminant is the ratio between light flux produced and energy expended; but this is not all; the life factor must not be neglected. Under some conditions, the total burning hours afford a fair valuation of the life. Usually, however, there is some point in the life of the lamp at which its usefulness may be considered to be exhausted, either because it has become too dim or because it has become too inefficient or because it has become unsightly. The problem is to determine this useful portion of life. Since first suggested by O'Keenan, the smashing point of lamps has been computed by many people. The method is based upon the considerations (1) that as the burning hours increase, the first cost of the lamp is divided among a larger number of hours and as an element of cost per hour becomes less important and (2) that as the burning hours increase, the watts per candle increase. The net result is that the cost per candle-power hour decreases with hours of burning due to the lessening influence of the first cost and later increases because of the increasing watts per candle. It follows that for any rate for current, cost of lamp and lamp performance characteristic, there is some number of hours at which the curve of cost per candle-hour reaches a minimum. This number of hours is said to correspond to the economical life of the lamp. Such curves of cost per candle-power appear in fig. 9.

The 80 per cent. criterion appears to have been adopted originally as a practical measure, based upon the requirements of the situation, rather than as a value arrived at by means of computations of economic life. It can be justified to-day only as such. This statement is based upon the following considerations:

(1) The exact location of the "smashing point" varies with cost of energy and cost of lamp.

(2) The cost per candle-power varies but slightly with increasing hours in the neighborhood of the "smashing point."

(3) A "smashing point" suitable for one type of lamp operating under one set of conditions is not suitable for all other types or sizes of lamp operating under the same conditions.

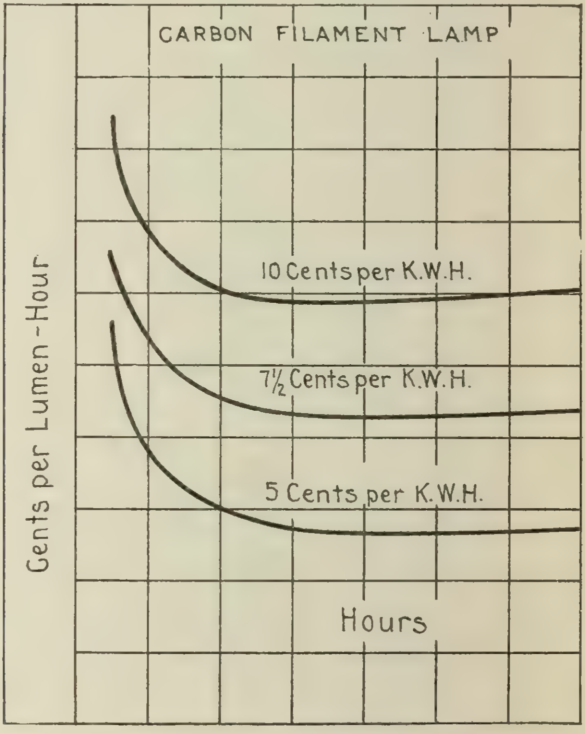


Fig. 9.—Illustration of methods of determining "smashing point."

(4) Slight differences in candle-power which affect the useful life largely are not perceptible in practice.

In view of these facts the 80 per cent. criterion claims attention simply as a limit of permissible candle-power decline adopted in the interests of good service and for the purposes of life testing. As such the authors endorse it, believing that it would be difficult to select a more suitable limit, and finding little or no reason for advocating a change from a limit already so well established. However, in endorsing the 80 per cent. criterion

as a limit of permissible candle-power decline, the authors do not wish to be understood as endorsing the existing practise of applying such limit to an evaluation of "useful" life. In fact it is in the belief that this criterion is improperly applied that this paper is written, with the purpose of pointing out the impropriety of the method and advocating a different method.

PROPOSED METHOD OF EVALUATING LAMPS.

Briefly, it is proposed that lamps be evaluated in terms of their lumen-hours or candle-hours per watt throughout the test period divided by the hours in such period, the hours to be arrived at by methods discussed hereafter.

In order to test this system it is proposed to apply it to the illustrations of lamp performance given previously in this paper. A test period of 600 hours is selected arbitrarily for the study of these illustrations. Here, as in the later discussion of test period selection, adherence to the 80 per cent. criterion is the governing consideration. Again, for the sake of simplicity the watt element is omitted.

Referring to fig. 4, the performance of the two lamps there shown are compared by the conventional and the proposed methods in the following table.

Lamp No.	Conventional method. Hours "Useful" life	Proposed method Per cent. of initial lumens throughout 600 hours
47	615 hrs.	91.3%
79	430 "	87.0%
Indicated superiority for No. 47	43%	5%

Surely in comparing the performance of these two lamps a 5 per cent. superiority attributed to No. 47 is a reasonable result, and as surely a 43 per cent. superiority is an unreasonable result.

A similar analysis of the performance of the two lamps shown in fig. 5 is as follows:

Lamp No	Conventional method. Hours "Useful" life	Proposed method. Per cent. of initial lumens throughout 600 hours
Continuous line	545 hrs	90.4%
Broken line	738 "	91.2%
Indicated superiority of of latter	35%	1%

In this case the performance of the two lamps is substantially

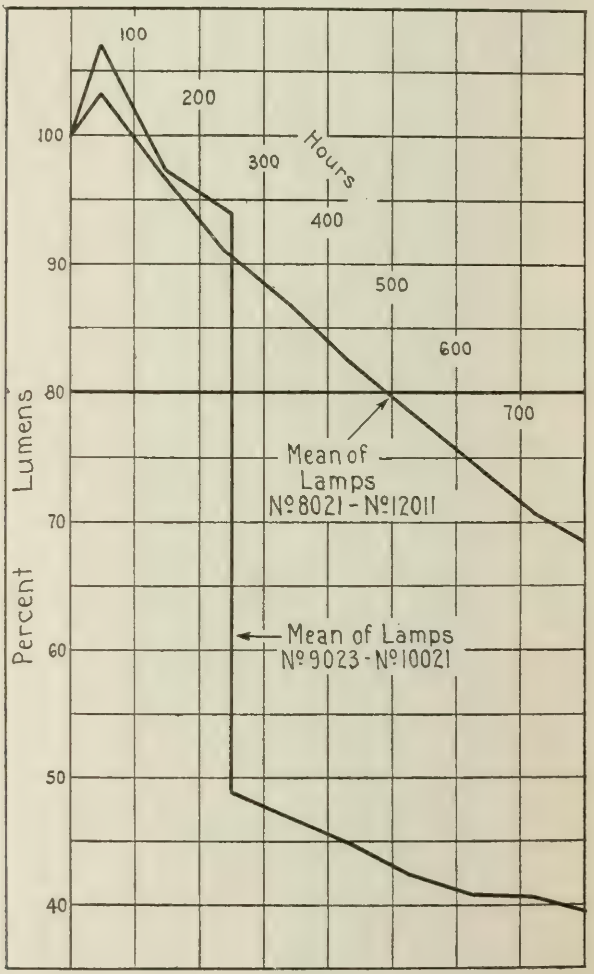


Fig. 10.—Average performance of two pairs of lamps the individual performances of which appear in fig. 6.

equivalent and a difference of valuation amounting to 35 per cent. is fictitious and unwarranted.

Figure 6 affords a simple comparison of the performance of

two groups of lamps. These performances appear in the form of mean curves in fig. 10.

Studied by the standard and proposed methods they yield the following results:

Lamp No.	Conventional method. Hours "Useful" life	Proposed method Per cent. of initial lumens throughout 600 hours
9023	746 hrs.	95.3%
10021	248 "	40.9%
Mean	497 hrs.	68.1%
8021	497 hrs.	89.2%
12011	497 "	89.2%
Mean	497 hrs.	89.2%
Indicated superiority of second group	None	31%

As previously noted during 350 hours a superiority of less than 10 per cent. on the part of one lamp exactly compensates for an inferiority of 100 per cent. on the part of the other lamp if the conventional method of evaluation be followed. The performance of the two groups of lamps is more readily appreciated from fig. 10, where the total yield in light of the first group is shown to be cut almost in half by the failure of one lamp at 248 hours. The proposed method results in a much fairer evaluation of the performances in showing the correspondingly reduced light intensity due to the complete failure of one lamp half way through life. There can be no doubt but that the two lamps of the second group are of considerably greater value than the two lamps of the first group in this comparison.

These examples of the application of the proposed method to performances of individual lamps show the unsuitability of the standard practise, while illustrating the reasonable nature of the valuation arrived at by the proposed method.

The important matter to be decided before the proposed method evaluation can be applied is the selection of a test period. For any one size and type of lamp the test period should be adopted after careful consideration of normal performance. It should cover the useful portion of the life and should be so selected as to serve the purposes of the parties interested in the test. Where no superior basis of judgment offers, it is suggested

that the test period be the average of (1) the hours at which the candle-power of surviving lamps has declined 20 per cent., and (2) the hours at which the mortality aggregates 20 per cent.

In this proposal the mortality rate is a new basis of consideration. Heretofore the rate of candle-power diminution alone has governed the useful period of lamp life and the failures within the period so selected have merely been noted, their shorter life values operating to reduce the final evaluation somewhat. The result has been that among different classes of lamps tests have been continued until the mortality has aggregated anywhere from 0 to 60 per cent. Evaluation has depended so largely upon the candle-power element that the burn-out element has been suppressed. Depending upon the viewpoint and upon conditions of operation, either element may be given greater weight; but for general purposes it would appear wise to attribute the same value to both important elements of performance, permitting the test period selection to be affected equally by one per cent. burn-out or by one per cent. candle-power decline.

If the hours at which 20 per cent. of the lamps fail coincide with the hours at which the surviving lamps decline 20 per cent. in flux the total yield of light from a group of lamps under test at such hours would be 64 per cent. of the initial value.

Having arrived at a test period by this method, it is proposed that the lumen hours or candle-power hours of the lamp during the period be divided by the hours in the period, and that the resultant mean value throughout the period be considered the measure of the value of the lamp throughout useful life. On this basis a lamp which failed half way through the test period would be given substantially half value. The measure so obtained would be a true measure of the performance of the lamp (neglecting watts) and would be as nearly a true criterion of the value of the lamp as the correctness of the selection of the test period might permit.

In comparing two groups of lamps the results would be such as would be obtained by employing a photometer to measure the intensity of illumination in two comparable rooms illuminated respectively by the two groups of lamps placed above diffusing

glass ceilings. One per cent. mortality would have the same effect as one per cent. flux decline among the survivors.

Taking the watt factor into consideration the proposal is to

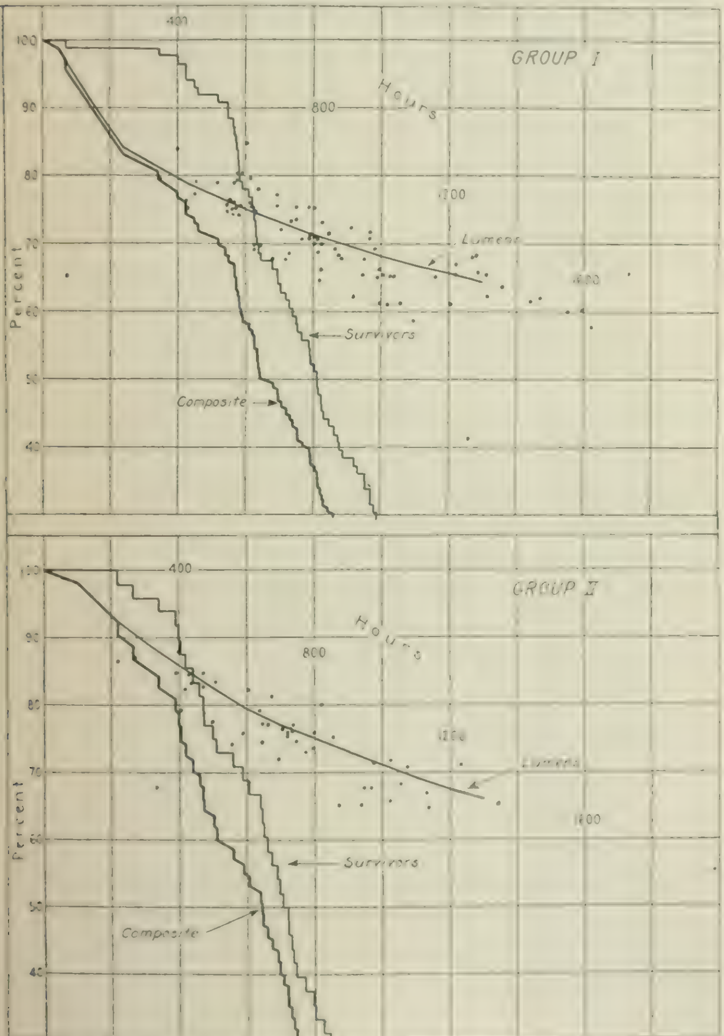


Fig. 11.—Details of performance of two groups of lamps. (Dots show hours of failures and lumens just prior to failure.)

determine the lumen-hours per watt throughout the test period, divided by the hours in such period.

To show the application of the method thus outlined, the results of test of lamps manufactured in two different factories are selected. Their performance is given in fig. 11.

The usual statement of test results covering these two groups of lamps would be about as follows:

	Group 1	Group 2
No. lamps tested	86	48
No. of burn-outs above 80%	3	12
Per cent, of burn-outs above 80%	3.5%	25.0%
Average life of burn-outs above 80%	522 hrs.	444 hrs.
Average life to 80% or earlier burn-outs	421 "	533 "
Indicated superiority		26%

In the diagram each dot indicates by its location the hours at which a lamp failed and the probable lumens shortly before failure. The average lumens of survivors throughout the test is indicated by the curve. The per cent. survivors at any time is indicated by the light jagged line. The heavy jagged line is a composite—the product of the two—showing for any period of the test the per cent. of initial lumens of the entire group of lamps.

In applying the proposed method of evaluation a test period must be selected. In the absence of other considerations, the proposal to be guided by the mean of the 20 per cent. flux decline period and the 20 per cent. mortality period is followed. Such mean values are 500 hours for group 1 and 517 hours for group 2. Roughly this leads to a test period of 500 hours. The average flux throughout 500 hours is ascertained to be 84.7 per cent. of the initial value for group 1 and 87.5 for group 2.

Here the conclusion is reached that the lamps of group 1, shown to be much inferior by the conventional method of evaluation, have evidenced only a slight inferiority as compared with the lamps of group 2.

Fig. 12 facilitates a comparison of the two groups of lamps and makes it apparent that in evaluating the lamps in accordance with standard practise the superior flux maintenance of the survivors of group 2 has received undue weight and more than compensates for the inferiority of the lamps due to early failures. The two heavy faced lines which represent the composite per-

formances of the two groups show clearly the early superiority of the lamps of group 2 due to better flux maintenance and their later inferiority after the total yield of light by the group has been reduced through the failure of individuals. Not only is it apparent that the lamps of group 1 have yielded 96.8 per cent. as much light during the 500-hour test period, but it is to

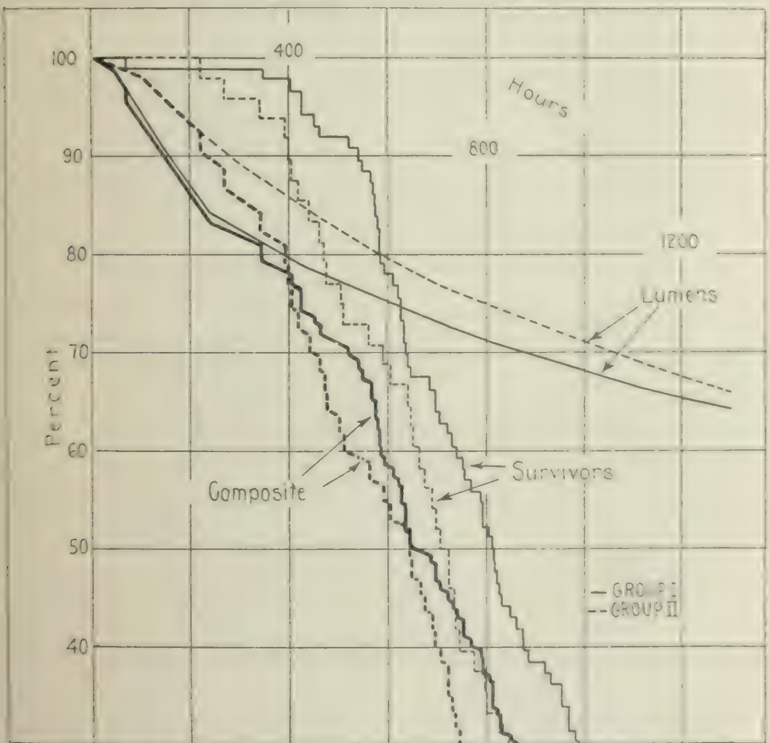


Fig. 12.—Comparative performance of the two groups of lamps details of which appear in fig. 11.

be noted that at the end of such test period they are better prepared to render satisfactory service because a larger proportion of them continue in operation at that time.

To make the analysis of the performance of these two groups complete, it remains only to consider the relative watt consumption throughout the test period. The data necessary to this comparison are shown in the following table:

	Group 1	Group 2
In per cent. of initial		
Average lumens throughout 500-hour test period	84.7%	87.5%
Average watts throughout the test period	96.5%	95.6%
Average lumens per watt throughout period	87.8%	91.5%

In the case here instanced, the factory where the lamps of group 1 were manufactured was actually subjected to running criticism for six or eight months because of alleged inferiority of this class of lamps, and neither the purchaser nor the manufacturer had the slightest doubt as to the very marked inferiority of the lamps which a closer and more accurate analysis has shown to be almost as good as the lamps from the other factory.

ADVANTAGES OF PROPOSED METHOD.

Wherever the proposed method or its equivalent is applied, lamp test results, being no longer subjected to the exaggerated effect of difference in flux maintenance as under the old method, will vary more in accordance with the true values of the lamps. Test errors, particularly errors in photometric measurements, will affect the final results very slightly, whereas under present practise the errors are multiplied many times. Improper selection of tests periods will affect the final evaluation to a lesser degree than similar improper selection of flux decline limits under the present method. But most important of all, the adoption of the proposed method will attribute more nearly correct importance to the burn-out element which under the old practise was somewhat obscured by too complete reliance upon the candle-power element of performance. This effect is apparent from a study of the following comparative data:

		At end of "useful" life (conventional method)		
Group	Hours "useful" life	Per cent. survivors	Lumens of survivors in per cent. of initial	Lumens of group in per cent. of initial
A	544	82.5	80.5	66.4
B	421	96.5	80.0	77.2

The table shows that at the hours which according to the conventional method of evaluation mark the end of the "useful" life of the lamps, the proportions of failures among the two classes are 3.5 per cent. for group B and 17.5 per cent. for group A.

Reference to the performance characteristics of the two groups of lamps shows that the inferiority of group A from the standpoint of early failures is balanced in the conventional method of evaluation by a superiority of approximately five per cent. in flux maintenance.

From the foregoing table it is apparent either that too short a "useful" life is assigned to group B lamps, or too long a "useful" life is assigned to group A lamps. It is unfair to group B to consider the "useful" life to have expired when only 3.5 per cent. of the lamps have failed, while permitting group A to continue to burn 123 hours or 29 per cent. longer, until 17.5 per cent. have failed merely because the candle-power of the survivors of group A is 6 per cent. higher. The 6 per cent. candle-power superiority balances a much larger percentage of mortality inferiority.

While it is contended that the lamps of group B should be continued on test longer than the present practice permits, yet to continue them until the burning hours equal the "useful" life of group A would be unwise because the survivors would be too low in flux at the end of such period. The proposed method of selection of a test period results in a 500 hour test period for group B, which appears to be a reasonable compromise likely to result in a fair evaluation of the lamps, for in such period the burn-outs would aggregate 8 per cent. and the lumens of survivors would average 77 per cent. of initial.

Where the proposed method is adopted, it will be logical to select for lamps of one and the same type which are designed for the same class of service test periods of like extent. If within such test periods the lamps of different sizes exhibit markedly different tendencies in either rate of flux decline or mortality, the efficiency should be altered to correct the undesirable tendency. This is a basis of efficiency adjustment which is believed to have points of superiority over any other basis which has been employed, and which is strongly recommended to those having jurisdiction in such matters.

DISADVANTAGES OF PROPOSED METHOD.

This proposed method carries with it certain disadvantages

which, however, are not peculiar to the method but are rather inherent in the problem.

One prominent difficulty in the way of the application of the proposed method is to be found in the necessity for selecting some test period to represent the useful portion of life. It is obvious that in appraising the life of a lamp at any value short of the total burning hours risk of undervaluing the lamp for certain classes of service is incurred. This is a risk which for general purposes it is desirable to take in order to secure a high standard of lamp performance which places a premium upon good flux maintenance and high efficiency and does not hesitate unduly in penalizing long drawn out life when such life involves relatively low candle-power and efficiency.

It is important to remember that there can be no more serious defect in a lamp product than an unduly large proportion of lamps which fail after a few hours of burning. Any system of evaluating useful or economic life of lamps is unsatisfactory to a certain extent because it credits the undesirable lamp which fails after a few hours of burning with one hundred per cent. of its maximum possible value under any conditions of service, while attributing to the long life lamp only a portion of the maximum possible value. It is difficult to conceive of any practicable remedy for this, short of a direct penalization system which would credit only a fraction of actual performance to the early failures among a product.

Under this proposed scheme the general objection may be raised that individual lamps may be permitted to run below 80 per cent. or may be removed from test before reaching 80 per cent. of initial candle-power. This is true but such performance must represent divergence from the normal and must suffer or profit to the extent that such divergence may affect the candle-power throughout the test period. Surely this is a minor objection largely academic in character and one which one need not hesitate to incur in order to avoid the grave consequences of the misleading character of the existing method.

CONCLUSION.

The authors have made extensive use of the conventional method of evaluating the "useful" life of lamps. They recognize

fully that this method is a logical and consistent application of the 80 per cent. criterion, wherever that criterion is held to be applicable to the performance of individual lamps. Some two years ago the tendency of this method to mislead began to be apparent, and since that time they have in many cases supplemented statements of "useful" life and candle-hours by statements showing for certain arbitrarily selected periods the mortality and candle-power of survivors. Often the extent of the error involved in the standard practise has been sufficient to mislead regarding the relative merits of competing products or of different types of lamps. Due to such difficulties, it seems wise to abandon a strict application of the criterion to the performance of individual lamps and without abating adherence to the criterion, apply it to the normal performance of each class of lamps in order to determine a test period.

As these proposals are somewhat at variance with well-established practise, it would be unwise to advocate any immediate change in method. Thorough scrutiny and discussion are first in order. Whatever the outcome of such discussion, the authors venture to express the hope that such change in practise as may be found desirable may be so effected as to continue the useful life idea without involving the practise in the unsatisfactory methods which are now standard.

DISCUSSION.

Mr. E. J. Edwards:—The question of the proper evaluation of a lamp is one always before the manufacturer and the user of lamps as well. From the standpoint of the manufacturer I can say that this subject is of particular interest. I am very glad that the question has been studied by Mr. Millar and Mr. Lewinson and that this paper has been presented at this meeting.

The question as to what is the proper evaluation of a lamp involves, it seems to me, two considerations: a consideration of what one might call desirability features; and cost. If one considers only desirability features then there can hardly be a question but that the decision should depend on the minimum value which would be allowable from the standpoint of good service. If nothing else were to be considered, the question to decide would be just what minimum candle-power could be

allowed in an installation and yet have the service considered good. The desirability exclusive of cost considerations can be properly expressed in hours to some per cent. candle-power.

When one comes to the question of cost, the evaluation of a lamp in my opinion is not in proportion to the number of candle-hours, as Mr. Millar and Mr. Lewinson have seemed to assume throughout their paper. The worth of a lamp to a customer cannot be measured in terms of the candle-hours that it will furnish during its life. If the lamp had stored up within it the energy which would be necessary to supply light throughout the life of that lamp, then its value could be measured directly in terms of candle-hours; but such is not the case. Consider the illustration, I believe it was figure 3, where one lamp showed one per cent. higher candle-power throughout the life as compared with another lamp. If the total cost of light to the customer using those two lamps is considered the difference in value of the two lamps is not one per cent. as is shown by the candle-hours. It is something which depends on the cost of energy. For this particular case, by a rough computation, I find that the eighty per cent. criterion is the nearer of the two in question and would hold exactly if the cost of energy were about two cents a kilowatt-hour. If the cost of energy is greater than two cents a kilowatt hour the difference is not less than four per cent., but is even greater, and for this particular case would be over ten per cent. Therefore, considering this one example alone it would seem that the eighty per cent. point would be a better criterion for evaluating this lamp than the one proposed by the authors of the present paper.

As I mentioned a moment ago the assumption seems to have been made all the way through the paper that the proper criterion, without question, is the candle-hours obtainable from the lamp out to a point in hours where the candle-power has fallen to a value where the light is no longer adequate. The main point I wish to make in this discussion is that it would seem to me from either the standpoint of desirability or from the standpoint of cost that this is not the basis which will give the true value to the user. In spite of the fact that the proposed method gives more accurate information, it happens that the old 80 per

cent. criterion gives values more nearly proportional to the true worth of the lamp.

I have noticed that the authors use the expression candle-power-hours per watt, and in looking over the paper I could not quite see from a dimensional standpoint why candle-power hours per watt would be a proper measure to use there. Perhaps they had some very good reason for putting it in that form.

Another question that I would like to ask is just about how the two methods, the one called the conventional method and the one called the proposed method, compare in the penalty applied to early burn-outs, a question which, of course, is of great importance.

Mr. Ward Harrison:—I agree with Mr. Edwards that if one simply wishes to rate lamps from the standpoint of desirability and good service the hours to 80 per cent. candle-power is probably as good a criterion as can be established; but if one wishes to determine the value of a lamp from a cost standpoint the question of candle-hours must be given consideration as is urged by the authors of this paper. It should be remembered, however, that the value of the energy consumed by a lamp far outweighs the cost of the lamps itself and no proper evaluation of lamp quality can be made without taking this fact into account. One may say that the average lamp user is interested in the results of comparative life tests only as they show him how to secure the most light for his money. The prospective purchaser when sending to the testing laboratory the two lamps whose life curves are shown in fig. 3 no doubt wished to learn which of these lamps would be the better, the more economical for him to buy and how much difference in price he could afford to pay for the superior product. If I have understood the paper correctly, it is the opinion of the authors that one per cent. properly represents the difference in value between the lamps, while the old method of rating shows four per cent. Personally I believe the difference is even greater than is indicated by the old rating.

Let us assume for example that energy cost 10c. per kilowatt-hour and that the lamps consume 50 watts each and have a useful life of 500 hours. At the end of this period both lamps will have consumed 25 kilowatt-hours, costing $2.50. If the

price of the better lamp is 20c., then the combined cost of power and renewals in this case will be $2.70. The poorer lamp will yield throughout the 500 hour period an average of one per cent. less light than the 20c. lamp and hence in order to give the same economy, should have a total operating cost of $2.673. Of this latter sum $2.50 is the fixed energy cost, practically independent of the quality of the lamp, and consequently but 17.3c. remains to be expended for the lamp itself. From the standpoint of economy therefore the difference in quality is fully 14 per cent. Similarly, in the case of the lamps cited in fig. 4, with an energy cost of 10c. per kilowatt-hour, one can afford to pay but 6.5c. for the poorer lamp, if it is to equal in economy of operation the superior lamp selling at 20c.

Obviously, since the results of the preceding calculations depend to a large extent upon the rate for energy, it cannot be stated that the difference in value of the lamps in the two groups taken above will always be as much as 14 per cent. and 67.5 per cent. respectively. On the other hand, but little calculation is required to show that in no practical case, where lamps are operated at, or near their proper efficiency, will the difference in quality be less than five times the figure given by a simple comparison of candle-hour areas. In the majority of cases it will be at least 8 or 10 times as great as is indicated by such a comparison and not until the cost of energy is reduced to zero will the difference in lamp value be as small as the difference in candle-hour area. What a simple comparison of candle-hour areas really signifies from a cost standpoint is the reduction in the total expense of producing light made possible by new developments in lamp manufacture. A table illustrating this use of candle-hour areas was given in the paper by Mr. Randall[1]. It might seem inadvisable however to record the results of comparative life tests on incandescent lamps of the same general type, in such a form as would tend to minimize differences in quality in a form which might easily be made to convey a misleading impression to the casual observer.

[1] J. E. Randall—Recent Developments in Manufacture of Incandescent Electric Lamps—Trans. I. E. S., vol. 6, p. 626.

Mr. J. W. Howell:—The paper presented by Messrs. Millar and Lewinson to my mind is a very important one; in fact, a revolutionary paper. In the General Electric Company we have been testing lamps for a good many years, by the old eighty per cent. method of termination of life, and have always thought that the results produced were approximately correct. Now, Mr. Millar proposes a new method, and I admit that the method gave me a shock at first, and I presume it is the conservatism of the human mind not to like to be told that what they have believed to be right for fifteen or twenty years is wrong. There is a great deal to be said in favor of the present proposition and great deal to be said against it. The principal point of the paper, and the only one that I will discuss at all this morning is the proposal to change the period of terminating a test from a period of candle-power to a period of hours. To my mind the termination by candle-power is the natural one, while the termination by hours is arbitrary. Lamps fail or become useless for two reasons: first, they break—of course a lamp broken is useless thereafter; and second, they lose their usefulness because they lose candle-power. These are the only two methods by which lamps become of less value or become useless. Now, the old method of value follows the natural lines of these two methods of failure. In other words, one compares lamps by the time at which they break and second, if they don't break, by the time at which they lose a definite amount of their candle-power. Now, that may be wrong, but it has served a very, very good purpose in the past. As Mr. Millar has shown you, the old method makes a greater difference in the assigned values than the new method, because the old method makes a poor lamp poorer than the new method and it also makes a good lamp better. Now, that all tends to improve the quality of lamps even if it is exaggerated; and if the old method makes a poor lamp appear even poorer than it really is, it has served a good purpose. It has had the effect of making the candle-power better. If the new method had been in use from the start I venture to say that the progress in candle-power maintenance would not be as rapid as it has been.

Now, this subject is a very important one. We can't decide it

here by talking about it. It requires careful thought and study. The method has been presented to the Illuminating Engineering Society and very properly, I think, because it is immediately in the domain of the illuminating engineers to settle points of that kind. It requires very careful consideration, and I think it affords an opportunity for this society to make the initial move in bringing this question before the scientific world. I think it would be well if this body should appoint a committee who would consider this matter carefully, and put in as definite shape as possible, with our recommendations, so that it might be presented to the other societies for their consideration. I think it is a very important matter and should be pushed along..

Dr. E. P. Hyde:—The question of testing lamps is one that has been and always will be of considerable importance. It seems to me that if there is a proposal to change the method of testing lamps it is a question of standardization. The Illuminating Engineering Society took a very active and prominent part in the establishment of an international unit of candle-power, and it seems to me that this is a question that ought at least be put before the standardization committee of our own society. I would, therefore, make a motion, if it is in order, Mr. Chairman, following the suggestion of Mr. Howell, that the paper of Mr. Millar and Mr. Lewinson be referred to the committee on nomenclature and standards of the Illuminating Engineering Society with the suggestion, that if that committee deems it advisable the committee appoint a sub-committee to discuss the question and present a report recommending the adoption of what seems to that committee a suitable method of testing lamps.

The latter resolution was adopted.

Mr. P. S. Millar (in reply):—Mr. Edwards has introduced the element of operating cost and has expressed surprise that it was not considered in the paper. The authors have considered that the evaluation of lamp life and the determination of operating cost were separate and distinct propositions. Lamp testing is an important commercial matter. Broadly, its function is to determine normal lamp performance for each class and type of illuminant in order that the engineer may have data upon which to base his computation of operating cost. The engineer utilizes

normal performance data obtained in this way to determine whether, for instance, he will employ carbon, or tungsten lamps. The problem discussed in the paper is rather that of properly evaluating small variations from such normal performance on the part of any given type of lamp. We are discussing the evaluation of lamp life rather than of lamps themselves.

Mr. Edwards inquires concerning the "candle-power per watt" phrase. Our proposal is to consider the efficiency, that is the candle-power per watt, of the lamp throughout the test period. When all lamps to be compared survive the test period, the candle-power per watt throughout the period suffices. If some of the lamps break before the expiration of the test period, the proposal is to determine the candle-power per watt throughout the life of each lamp and to multiply such value by the ratio between the hours burned and the hours in the test period.

Mr. Edwards inquires further concerning the penalization of early burn-outs under the conventional and proposed methods. So far as I can ascertain either from theoretical considerations or application of the method, there is no substantial difference in the evaluation of lamps which burn out early in life. The chief difference between the two methods is to be found in the exaggerated importance of a slight superiority in candle-power maintenance of survivors under the conventional method. As stated in the paper, it is usually found that when there is a somewhat superior candle-power maintenance of survivors, there is an exceptionally large proportion of early burn-outs in the product. Under the conventional method of evaluation the exaggerated importance attributed to such slight superiority in candle-power maintenance of survivors often entirely covers up and conceals the early burn-outs in the product, resulting in a false valuation.

Mr. Howell has stated that a candle-power termination of the useful life period is a natural one. With this statement we must agree. It is only because difficulties have been experienced in the practical application of this idea that we have suggested a departure from the present method. As it is, the proposal in this paper contemplates adherence to the 80 per cent candle-power termination for the normal performance of a type of lamp, but proposes abandoning it and substituting a termination of a

certain number of hours for application to the performances of individual lamps.

Mr. Howell has stated also that even if the present method does attribute exaggerated value to small differences in candle-power maintenance, such exaggeration is a good thing, as it gives the manufacturer an incentive to improve. It should be noted, however, that such incentive is present only when the candle-power maintenance is unsatisfactory. When the candle-power maintenance is good, the incentive is lacking and the particular objection which the authors have urged against the present method is that a fair candle-power maintenance compensates for great inferiority in the matter of early burn-outs. Mr. Howell spoke yesterday of the unsatisfactory performance of Gem lamps of early manufacture, and stated that these features which were unsatisfactory have since been done away with. He will undoubtedly recall that in the case of the Gem lamp product mentioned, the chief unsatisfactory feature was early burn-outs; the survivors maintained the candle-power rather better than did carbon filament lamps. The consequence was that under the present method of evaluation the useful life of the Gem lamps was found to be superior to that of the carbon lamps, notwithstanding the large proportion of early burn-outs in the product. In this case the manufacturer should have had a great incentive to improve the product, but as far as test results went this incentive was lacking, because the good candle-power maintenance of the survivors more than compensated for the early burn-outs. We all know that American lamp manufacturers do not need a falsification or an exaggeration of records in order to afford the necessary incentive to improve the product. The marked improvements which have been effected in Gem lamps substantiate this. On this account, as well as on broad general principles, we submit that Mr. Howell's argument in this particular should be thrown out of court.

Mr. Harrison's discussion consists largely of an amplification of the points raised by Mr. Edwards and already mentioned.

Mr. G. S. Merrill (Communicated):—The importance of taking into consideration both candle-power performance and distribution of burn-outs in judging incandescent

lamp quality can not be too strongly emphasized. For several years the engineering department of the National Electric Lamp Association has been using "mortality curves" or curves showing percentage of lamps burning after various periods of time as an important adjunct to the familiar life candle-power curves in judging lamp performance.[1] We had hesitated however to adopt any method of figuring comparative performance which would measure quality in abstract numbers for the very reason mentioned in the third paragraph of the paper under "Disadvantages of Proposed Method." In commercial service early burn-outs are a serious matter and it is difficult to devise a method which will properly adjust the penalty for such failures. Although we have considered the candle-power and mortality curves individually in judging performance, we have made extensive use of curves obtained as products of the both candle-power and mortality and of wattage and mortality in evaluating lamp performance for calculations of most economical operating efficiency.

In order to thoroughly investigate the economic possibilities of any particular kind of lamp it is necessary to have complete knowledge of what they will do when burned under certain known conditions. One must know the candle-power maintenance and the change in wattage with burning and finally one must not be content to base his calculations alone on an average life obtained from tests on a large number of lamps, but must know just how the burn-outs have been distributed during the period of service. We have therefore arrived at a method of evaluating lamp life for the purpose of "best efficiency" calculations which is similar to that used by the authors of the paper under discussion for the purpose of comparing the quality of different lamps. Not only have we used product curves of candle-power and per cent. lamp burning in these calculations to show the total luminous output of a group of lamps at any period of burning (considering that no renewals are made as the lamps burn out) but we have also used product curves of wattage and per cent. lamps burning to show the corresponding energy consumption of the group of lamps under consideration.

[1] A mortality curve (or as it has been termed in the article under discussion a curve of "survivors" was used by the writer in showing lamp performance in a paper presented at the Toronto section, A. I. E. E., Nov. 16, [illegible]

By using such a comprehensive method of evaluating lamp performance it is not necessary to base the calculations on an average life to any arbitrarily assumed smashing point, as has been generally done in "best efficiency" calculations. The final results obtained by this fundamental method of analysis for any particular case may be summarized in tabular form as follows:

TOTAL COST PER 1,000 MEAN SPHERICAL CANDLE-HOURS.

40-watt, 110-volt tungsten lamp. Lamp cost 70c. Equivalent energy rate 10c. per kw-hr. Life calculated to different smashing points or previous burn-out.

Smashing point per cent. horizontal c-p. (individual)	Initial efficiency watts per mean horizontal candle				
	1.00	1.10	1.15	1.20	1.25
90	24.0c.	21.6c.	20.9c.	20.6c.	20.5c.
85	21.2	19.9	19.6	19.5	19.6
80	19.8	19.0	18.9	19.0	19.2
75	18.8	18.5	18.5	18.8	19.1

Figures tabulated in this way are more instructive than if based upon the life to any arbitrarily assumed smashing point or previous burn-out.

Mr. M. D. Cooper (Communicated):—On the fourteenth page of the paper is the statement that "The exact location of the 'smashing point' varies with the cost of energy and the cost of the lamp." I do not wish to criticise that statement, for under the conditions stated, it is absolutely true. I do desire, however, to amplify it with the conclusions of some calculations regarding "best efficiency." These calculations were based upon the three elements: Candle-power maintenance, wattage consumption, rate of mortality. It was found that the smashing point for a given type of lamp varied with the rated efficiency of the lamp. For some particular efficiency and some particular smashing point, however, the average cost per unit of luminous output is an absolute minimum. The peculiar feature encountered was that the smashing point required to give an absolute minimum cost of light is practically independent of the cost of lamp and the cost of energy. The following data demonstrates an example of this.-

40-WATT TUNGSTEN LAMP.

Assumed costs		Conditions required for an absolute minimum cost of light	
Energy per kw hr.	Lamp	Initial w. p. c.	Smashing point (% of initial c-p.)
10 c.	50 c.	1.06	75
10	70	1.12	76
5	50	1.17	76
5	70	1.23	76
		Average......	76

The following average data for other sizes and classes of lamps may be of interest.

	Smashing point (per cent of of initial c-p.) required for absolute minimum cost of light for any cost of lamp and energy (proper efficiency being assumed)		
Wattage	Carbon	Gem	Tungsten
25	62	—	—
40	—	61	76
50	62	65	—
60	—	67	75
80	—	65	—
100	68	67	78
250	—	—	74
500	—	—	73
Average........	64	65	75

Messrs. P. S. Millar and L. J. Lewinson (communicated):—In the discussion at Chicago Messrs. Edwards and Harrison introduced operating costs as a basis of determining relative values of lamps. In reply the authors stated that as the paper dealt with methods of evaluating life performance for life testing purposes, considerations of operating costs were not pertinent. It is desired at this time, however, to comment briefly upon these statements.

Notes on Operating Costs. The views of Messrs. Edwards and Harrison may be indicated by the following paraphrase:—

Assuming a 500-hour useful life (50-watt lamps), energy at 10 cents per kilowatt hour and a lamp price of 20 cents, the cost of current would be $2.50, the cost of the lamp would be 20 cents and the total operating cost would be $2.70 for each lamp. To get the same economy of operation, i.e., equal cost per candle-power hour, the total operating cost for the lamp which is deficient by one per cent in candle-power would have to be $2.673 instead of $2.70. With both lamps the energy cost is fixed at $2.50. Hence if the same cost of operation is to be had, the consumer can afford to pay no more than 17.3 cents for the poorer

lamp as against 20 cents for the better lamp. This is a measure of the value of the two lamps and the difference is therefore about 14 per cent. in value.

The method here contemplated determines the difference in operating economy and evaluates lamps by ratios between such differences and the first cost of the lamps. If this principle were to be accepted, the difference in values of the two lamps would be as follows for various hours of burning under the same assumptions of current and lamp costs—

100 hours	3.5%	difference in value.
500 hours	14%	difference in value.
1000 hours	29%	difference in value.

If the difference in candle-power were 7.4 per cent. instead of one per cent, the value of the inferior lamp would be stated as zero.

These comparisons indicate the indecisive character of the measure of value afforded by the method employed by Messrs. Edwards and Harrison. Such large variations in conclusions must follow when all the difference in operating economy is charged against a relatively small element of the total operating cost. It is very difficult to see why the first cost of the lamps should bear the entire burden of such differences in operating economy. It is treated in this way because the speakers stated that the cost of current was fixed and that therefore the other element, the cost of the lamps, must bear the burden. As a matter of fact the cost of the lamps is fixed as much as is the cost of current. It would be just as logical and just as reasonable to say that the cost of the lamps being fixed, one could afford to pay for the current only ($2.50—$0.027=) $2.473, which shows that the value of the inferior lamp is $\frac{(\$2.50 - \$2.473 =)}{\$2.50}$ 1.08 per cent. less than that of the other lamp.

As a matter of fact both the cost of the lamp and the cost of the current must be assumed to be fixed. The only practicable and reasonable procedure in computing differences in value based upon operating economy is to show the fixed total operating cost in terms of the light produced by the two lamps.

If it be assumed that lamps are to be valued on the basis of operating economy, the answer seems very simple:

	Lamp No. 1	Lamp No. 2
Light produced	100%	99%
Cost of lamp	20c.	20c.
Cost of energy	$2.50	$2.50
Total operating cost	2.70	2.70
Ratio operating cost to light produced	2.70	2.727
Difference in value	1%	

It appears obvious that 100 of the poorer lamps would give the same lighting service as 99 of the better lamps, but with a difference in operating cost amounting to about one per cent. Given lamps which yield about one per cent. less light for the same operating cost, or the same light for about one per cent. greater operating cost, it is difficult to see how an evaluation based upon operating economy can result in other than a difference of about one per cent.

THE EFFECTIVENESS OF LIGHT AS INFLUENCED BY SYSTEMS AND SURROUNDINGS.[1]

BY J. R. CRAVATH.

The efficiency of various artificial lighting systems is frequently expressed in the percentage of the total lumens generated which reach a given working plane. Such information must always be of fundamental importance and it should be the constant effort of the illuminating engineer to get more imformation. However, it has been recognized for some time that the illuminating engineer must go a step farther and study the relative effectiveness or efficacy of the lumens delivered by different methods and with different surroundings as well as with different individuals. To put the problem in another way: will a foot-candle of illumination intensity delivered on a given part of a working plane be as effective in enabling a person to see clearly under one set of surroundings and conditions as under another? How is visual acuity affected by the color and illumination of surroundings, by glare from lamps in the field of vision, by glare or shadows on the work, or by personal peculiarities. A high efficiency avails nothing if it is accompanied by such characteristics as make vision uncomfortable or inconvenient. These questions have a very practical bearing on the design and arrangements of illumination system in every-day practise.

The author has been questioned frequently as to the comparative effectiveness of direct and indirect lighting systems as at present commonly installed, and whether indirect installations should be figured for a higher or lower foot-candle intensity than direct installations? Plenty of theory but very few facts may be found on these questions. The principal scientific investigations bearing upon them would lead one to rather conflicting conclusions. It has been a matter of common observation for years that a bright light near the center of the field of

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25. 26, 29 and 28, 1911.

vision seriously interferes with one's ability to see clearly. Mr. A. J. Sweet has reduced this knowledge to exact form, as far as conditions which prevail in street lighting are concerned, in his investigations which were reported in a paper which appeared in the *Journal of the Franklin Institute* for May, 1910. He found under those conditions that a light within twenty-six degrees of the center of the field of vision necessitated higher illumination on the object viewed. Mr. Preston S. Millar in 1910 got somewhat similar results.[1]

On the other hand Mr. Preston S. Millar in his paper before the 1907 convention of the Illuminating Engineering Society on the "Elements of Inefficiency in Diffused Lighting Systems" showed that under certain conditions a number of persons tested required about 65% more foot-candles on the reading page with a certain indirect system than was required with a direct system. While the author has never questioned the accuracy of the results obtained by Mr. Millar, he has felt that the indirect lighting installation used by him for the test produced such abnormally bright walls that it did not represent a commercial indirect equipment as used extensively to-day and that further tests ought to be made on this point.

Another difficulty encountered in calculating illumination has been the difference between persons as to the illumination required for a given work. This has been especially troublesome in practise where the illumination of a large general office is dealt with. Certain individuals apparently require much more illumination than others. A question arises, therefore, as to what are reasonable and what are unreasonable requirements in this respect, or, what constitutes abnormal requirements?

Very little has been known as to the influence of surroundings on the illumination required. It is of course known that when the eye becomes accustomed to very low illumination as at night, it can discern objects which could not have been seen before the eye became adjusted to the darkness. It has not been known, however, what effect light-colored walls, for example, have upon the illumination required for doing certain work as compared with the illumination required with dark colored walls within the range of ordinary commercial work. The experiments of

[1] *Transactions Illuminating Engineering Society*, [illegible]

Mr. Millar just referred to on indirect lighting seem to show conclusively that under certain extreme conditions walls of light color highly illuminated necessitate a higher order of illumination on the work. Little has been known, however, as to how far this principle applies to ordinary commercial conditions with artificial illumination. In opposition to the principle just mentioned, several authors have pointed to the fact that the eye like the photographic camera obtains a sharper and clearer picture when the iris or diaphragm is contracted to a small opening. Since the iris would naturally open wider amid dark surroundings, vision would not be as clear because of the spherical aberration of the eye. This, it has been argued, would necessitate higher illumination on the work amid dark surroundings than amid light surroundings.

On account of the importance of the various questions which have been outlined, the tests herein described, which were carried out under the supervision of the author, were undertaken to throw some light on these subjects and pave the way for further investigation. They are of necessity incomplete, but enough data have been obtained to point to some very interesting and important conclusions.

THE TEST ROOM.

These tests were conducted in a room 18 feet 8 inches by 21

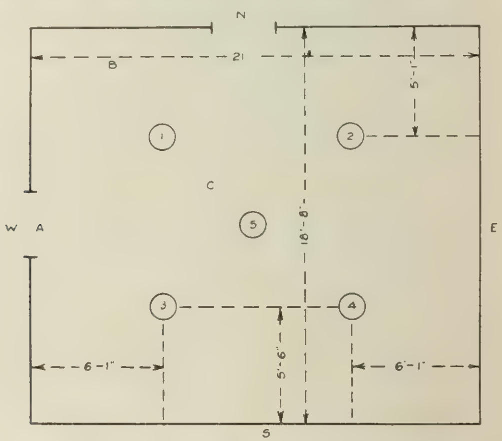


Fig. 1.—Diagram of room in which tests were made.

feet long. The ceiling height was 10 feet. Being a basement

room, all daylight was excluded. The only openings were two doors, which were closed with dark green portieres. The accompanying drawing shows a plan of the room. The ceiling and walls were of ordinary smooth plaster very light cream in color; the floor color was reddish brown. The furniture consisted of several desks and a row of dark colored transfer file cases about 30 inches high along the south wall. There were five outlets as shown, of which No. 1, 2, 3 and 4 were located in the approximate center of the four quarters of the room respectively. Outlet No. 5 was in the center of the room. In some of the tests as described later only the center outlet was employed. In other tests only the outlets in the four quarters No. 1, 2, 3 and 4 were employed.

TESTING THE LIGHT REQUIRED FOR READING.

The method employed in testing the amount of light required for reading purposes by different individuals was as follows: The person under test, who will hereafter be referred to as the subject, was seated at a flat top desk in such position as to read comfortably and naturally a column of the ordinary reading print from the *Saturday Evening Post*. The paper was always laid flat on the desk top. Just alongside the paper was placed the test-plate of a Sharp-Millar photometer to measure the illumination. As far as the position of the paper and the subjects were concerned, the conditions corresponded closely to those of a person working at a flat top desk with the work directly in front on the desk. The routine which was followed for each reading was as follows: A rheostat was inserted in series with the lamps of the system under test and the lamps were first dimmed to a point below which reading was uncomfortable. The illumination was then gradually raised by cutting out resistance until a point was reached which the subject considered the minimum value of illumination which would permit of comfortable continuous work. The subject was instructed to select the point at which he would be willing to work continuously if the lighting was costing him considerable money, but nevertheless a point at which he would be willing to work continuously. After this point was measured by the photometer the illumination was again raised and the subject was instructed to select the value

of illumination which was ample without being wasteful. After this value was reached and read on the photometer, the illumination was again lowered and the same process repeated. Three preliminary tests which were not recorded were taken on each subject to allow him to become accustomed to the routine and also to allow his eyes to become accustomed to the change from daylight to artificial light, as these tests were made during the day time. Ten recorded readings were made with each subject in each test except where otherwise noted. The subjects with but one exception were men interested in illumination. All but one were selected with a view of absolute freedom from any prejudice which might be caused by commercial connection with any system or method of lighting. One subject was tested who might naturally be expected to have some such unconscious prejudices affecting his result, but as his tests corresponded so closely to those of the majority of others, his results are included among the others as giving added confirmation to the conclusions reached.

Following is a list of the tests conducted on each subject after the manner before described.

In test No. 3, an indirect lighting fixture with cone-shaped one-piece corrugated mirror reflectors pointed upward was hung in the center at outlet No. 5. The desk was placed directly under this fixture. In this test the highly illuminated ceiling was practically out of sight of the subject.

In test No. 4, outlets Nos. 1, 2, 3 and 4 in the four quarters of the room were each equipped with tungsten lamps having the center of the filament about twelve inches from the ceiling and covered with prismatic reflectors giving an intensive distribution. The desk was placed at *A*, just inside the west door, as shown on the plan. The subject therefore sat facing four direct lighting units and the conditions were similar to those of a person working at a desk in a fairly large room lighted by this system. In the ordinary reading position of a subject in this test, the head was inclined forward enough so that the eyebrows shaded the eyes and the direct light from the units did not enter the eye. Whenever the subject looked up, however, the four units came within the range of his vision.

In test No. 7, outlet No. 5 in the center of the room was equipped with a tungsten lamp about twelve inches from the ceiling with a prismatic reflector giving an extensive type of distribution. The reading desk was placed directly under the lamp in the center of the room.

In test No. 8, indirect lighting fixtures were hung from outlets Nos. 1, 2, 3 and 4 in the four quarters of the room. The desk was located at *A*, just as in test No. 4, and the subject therefore upon looking up had the lighted ceiling over the four indirect lighting fixtures within the range of his vision, instead of the direct light from the lamps and reflectors as in test No. 4. As far as the subject was concerned, the conditions in this test also were similar to those in a large office using a similar type of illumination.

In test No. 9, a drop cord was hung from the center outlet No. 5 and an opaque desk reflector was hung about seven inches above the desk which was placed in the center of the room. Black curtains were hung around the desk so as to have the surroundings of the subject entirely dark, except the small area of desk, paper and photometer plate immediately under the reflector. Conditions in this test were rather unusual, although they are sometimes encountered in offices and industrial establishments. The object of this test was of course to determine the influence dark surroundings might have on the illumination required.

The results from these tests are given in the two accompanying tables, one of which gives the foot-candles considered ample and the other the minimum required for comfortable reading. The results are not averaged, as it was not thought proper to average results in such cases. Some of the most important comparisons to be made from "ample" table are as follows:

Test No. 9 represents the extreme of dark surroundings and localized lighting; while test No. 8 represents the extreme of diffused lighting and light surroundings. Out of eleven subjects undergoing both these tests, ten required much more with localized lighting and dark surroundings as in test No. 9. One required very much less. This one exception is rather remarkable, in view of the decisive results to the contrary obtained from

the ten other subjects. One might attempt to explain this by assigning it to a difference in eyes, but the author is inclined to think the cause lies elsewhere. Dr. Black on whom these exceptional results were obtained, read his paper from a much more acute angle as measured from the plane of the paper than did the other subjects. As a result he got much less of the effect of glare or regular reflection from the paper. Further comment will be made on this later in connection with other results.

A comparison of test No. 3 (indirect lighting directly over the subject) with No. 7 (direct lighting directly over the subject) shows that of ten subjects making these two tests, five required more illumination in No. 3, with the indirect lighting, and five required more in No. 7 with the direct lighting. These results are therefore inconclusive and indicate if anything no difference.

A comparison of test No. 4 and No. 8 should show the effect of the four indirect units in the four quarters of the room as compared with the four direct units similarly placed. Out of ten subjects taking this test, seven required more illumination with the direct lighting in test 4.

A comparison of test No. 3 and 8, namely indirect light over the desk in the center as against indirect light in the four quarters of the room and the desk near one wall, shows that out of ten subjects taking this test, eight required more illumination in test No. 3, with indirect light coming principally from overhead, than in test No. 8, with indirect light coming from the entire ceiling in front of the subject and therefore with a more thorough diffusion of light throughout the entire room.

A comparison of tests No. 7 and No. 4, namely direct light over the subject in the center of the room versus direct light from units in four quarters of the room, tends to confirm the foregoing statement inasmuch as six out of ten subjects required more light with the desk under the lamp in the center of the room.

These tests show that within the range of commercial practise there is nothing in the theory that the eye requires less illumination on the work amid dark surroundings or with dark walls than amid light surroundings with good diffusion of light; in fact quite the reverse. While doubtless extreme conditions can be produced as in the experiment of Millar previously re-

ferred to, where the brightness of surroundings necessitates an increase of intensity on the work; such conditions do not come within the range of ordinary practise

The author believes the explanation of the results obtained from these tests is to be found mainly in the matter of glare from the paper of the reading page. The paper selected for these tests is one which is notably free from glare. That is the print on it can be read with the paper at almost any angle under direct artificial light; whereas the print absolutely vanishes in some positions with the majority of smooth half-tone papers used in our monthly magazines. Nevertheless, the quality of light has a notable influence on the comfort of reading even the paper with which these tests were made. In the case of the shaded direct light with all surroundings dark, where such high intensities were required by the subjects with one exception, the light all came to the page from one general direction. The result was that the subject received a certain amount of harsh glistening effect from the paper. Although an attempt was made to place the paper in such a position as to reduce this glare as much as possible for the average subject, nevertheless it was noticed by the author that tilting the paper when held under the opaque reflector made a noticeable change in the character of the illumination and improved the comfort of reading. With the desk placed at one side of the room and with light falling on the paper from the large diffusing surface of the ceiling and walls, a minimum amount of glare effect was experienced. In other words the more complete diffusion of the light produced the soft effect which is a matter of common comment in indirect lighting and which is in contrast to the harsh effect of light coming from one direction from a single point. This so-called harsh effect is really regular or specular reflection from minute portions of the paper or other object viewed which act like mirrors. It may, of course, be argued that the conditions in these tests were not altogether normal in that the subjects were required to keep the reading page flat on the desk, whereas in practise the subject would ordinarily tilt the paper to the most comfortable angle. As regards reading alone, this would be true; but much writing and office desk work must be done flat on the desk on a certain

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definite plane and that system of lighting is most perfect which permits the worker to place his papers at any convenient angle without dodging the glare from the paper.

The theory that glare is largely responsible for the high illumination required in some of these tests is confirmed by a further study of them. Dr. Black, the only subject who required less illumination in test No. 9 than in test No. 8, read his paper from an angle which reduced the glare effect in test No. 9. Going a step further one observes that most subjects wanted more light on the paper when the desk was in the center of the room under the principal source of light than when the desk was at one side of the room. This applies to both systems of lighting. The author believes this is simply because of the greater glare effect in the center and the more perfect diffusion with the desk nearer the wall and a larger number of lighting units.

The test in which most of the subjects required the least illumination was test No. 8, in which the room was lighted from four indirect fixtures. The desk in that instance received light of the most diffused character.

Another point of interest to be noted in connection with these tests is that as a general rule the older the subject the higher the intensity of illumination required. Only two of the subjects wore glasses and neither of these because of age. Undoubtedly subjects fifty years old or more could have been found who would have required much higher illumination than that noted in the table. This is a factor to be considered in planning the illumination of large offices where many old employees are working.

GLARE A CONSTANT FACTOR.

While the foregoing tests were being conducted, some experiments were also made to determine whether the glare received from paper under certain conditions is dependent upon the total quantity of illumination falling upon it or is inherent in the character and diffusion of the light. Some highly sized paper was placed before each subject in the position which would give the maximum annoying glare and the illumination was raised and lowered in the attempt to find a comfortable point. No such point could be found and all subjects agreed that the glare

was equally annoying from the lowest to the highest illumination. From this one may deduce that the annoyance caused by glare is not caused by reflection from the whole sheet of paper, but from certain minute portions of the paper which are reflecting light to the eye much more than certain other immediately adjacent portions. It is the extreme contrast between the highly illuminated portions and the less illuminated portions between that makes reading impossible when glare is at its worst. Incidentally the author may remark that he believes that the annoyance caused by glare from light sources is altogether a matter of contrast with their surroundings. This has apparently been overlooked in many discussions of the subject.

It may be asked here why certain subjects required more illumination on the paper when receiving glare from it, if the glare was found to be independent of intensity of illumination. The author believes this is easily explained by the fact that the subject would naturally ask the illumination to be raised until he found a point which was comfortable for reading. As the glare introduced a certain fixed element of discomfort, the subject would naturally call for more and more illumination until he would realize that further attempt to secure more comfortable conditions by an increase were unavailing. As stated before, the glare received from the paper under test, even under the worst conditions, was not distinctly noticeable; but nevertheless it was to some extent present, though not generally recognized because it was not so bad as to prohibit reading.

The results obtained emphasize most emphatically the importance of diffused lighting similar in character to daylight if the illumination is to have that soft and satisfactory quality which will enable work to be done at any angle any place in a room or office, and serve industrial purposes. There need ordinarily be no fear of getting the illumination too shadowless, as shadows are present though unrecognized in both artificial indirect lighting and natural day lighting of interiors, and only by extraordinary precautions could shadows be eliminated if it were desirable to do so. While the shielding of light sources of high intensity within the range of ordinary vision will continue to be one of the essentials of good illumination, more attention should

be given in the future to this question of the quality and diffusion of light, so that it will be received on paper and polished surfaces from many directions after the manner of daylight and so eliminate the two most objectionable features of most modern artificial lighting, namely glare from work and sharp shadows.

The concealing and shielding of the light sources is of course more important in audience rooms, living rooms and all classes of interiors where persons sit for some time with the light sources within the range of vision than it is in work rooms and offices where the occupants at work naturally incline the head so that the eyebrows shield the eyes. In the latter places, however, the question of lighting the work with a soft diffused light is very important. The comfort of working under properly arranged indirect light which is making the indirect system popular for offices, where it has been properly tried, is undoubtedly due more to the diffused character of the lighting and the consequent absence of glare from the paper and absence of sharp shadows than to the concealing of the lamps themselves.

The investigations of Mr. L. B. Marks at various times reported in the TRANSACTIONS of the Illuminating Engineering Society, have strongly condemned the use of purely localized lighting with opaque reflectors and dark surroundings. The results here reported are an added condemnation of that system, and point to the broad general principle, which can be safely followed in illuminating engineering work, of obtaining working light from as large surfaces as possible, thus imitating as far as possible the diffuse lighting conditions existing in daylight.

GENERAL CONCLUSIONS.

The general conclusions to be derived from these tests and previous information are that under ordinary working conditions the diffuse character of the light falling on the work has more influence on the comfort of seeing and the amount of required illumination than the brightness of the surroundings. The greater the percentage of diffuse or indirect light and the less the percentage of direct light from small sources, the more satisfactory the system is likely to be for work under varying practical conditions. These conclusions apply only to conditions where there are no exposed lamps within twenty-six de-

grees of the center of vision, when the eye is centered on the work; because the brightness of lamps so placed doubtless causes annoyance and necessitates increased light on the work. Extreme brightness of surroundings with a diffusing lighting system may be produced experimentally, which will necessitate high illumination on the work; but for economical reasons such

TABLE OF FOOT-CANDLES CONSIDERED THE MINIMUM COMFORTABLE FOR STEADY READING.

Name of subject	Test number				
	3	4	7	8	9
Miss B. Hennessy	0.47	0.46	0.73	0.42	[illegible]
Albert Scheible	0.80	0.57	1.29	0.92	[illegible]
O. H. Caldwell	0.47	0.42	0.27	0.18	0.30
J. R. Cravath	0.89	0.91	0.92	1.12	2.00
Walter E. Lent	0.60	0.55	0.99	0.42	0.50
J. B. Jackson	0.47	0.45	0.68	0.30	0.50
S. E. Church	0.53	0.42	0.42	0.23	[illegible]
A. A. Keene	1.53	1.48	—	—	—
F. J. Pearson	2.23	1.38	1.73	0.69	[illegible]*
W. R. Bonham	0.59	0.66	0.49	0.19	0.44
Dr. Nelson M. Black	—	—	1.47	[illegible]	[illegible]*
H. D. Butler	0.64	0.46	0.85	0.44	1.45

* Less than 10 readings taken.

TABLE OF FOOT-CANDLES CONSIDERED AMPLE.

Name of subject	Test number				
	3	4	7	8	9
Miss B. Hennessy	0.76	0.72	1.37	0.735	2.43
Albert Scheible	1.28	1.03	2.37	1.92	11.96
O. H. Caldwell	0.80	0.81	0.58	0.39	[illegible]
J. R. Cravath	1.34	1.30	1.35	1.76	[illegible]
Walter E. Lent	1.39	0.99	1.68	0.69	0.93
J. B. Jackson	1.17	1.16	[illegible]	[illegible]	[illegible]
S. E. Church	0.87	0.68	0.68	[illegible]	[illegible]
A. A. Keene	2.06	2.12	—	—	—
F. J. Pearson	3.09	2.07	2.59	[illegible]	[illegible]*
W. R. Bonham	1.12	1.13	[illegible]	[illegible]	[illegible]
Dr. Nelson M. Black	—	—	[illegible]	2.17	[illegible]*
H. D. Butler	1.33	0.93	1.54	[illegible]	[illegible]

* Less than 10 readings taken.

Test No. 3. Indirect at center; desk in center.
Test No. 4. Direct in corners; desk at door.
Test No. 7. Direct in center; desk in center.
Test No. 8. Indirect in corners; desk at door.
Test No. 9. Shaded direct light; surroundings dark.

extreme conditions are not likely to be common as they would be costly and troublesome to produce commercially. On account of the impossibility of properly diffusing the light to secure comfortable illumination on the work, with dark surroundings, under ordinary conditions of use, the glare from the work practically more than contracts any gain in visual acuity in having surroundings dark.

The author wishes to acknowledge the courtesy of the National X-Ray Reflector Company, for whose information the tests mentioned were made, for permission to publish the results of the tests. And lastly the author also wishes to thank those who gave their valuable time and assistance in acting as subjects.

DISCUSSION.

Mr. P. S. Millar:—From a casual reading of Mr. Cravath's paper, I fell into some confusion regarding first, the author's purpose in making these observations, and, second, his conclusions as drawn from the observations. In view of the fact that some early work of my own is quoted at length, I presumed that Mr. Cravath aimed to study the effects of light surroundings upon the intensity requirements for reading. In fact it is difficult to reach any other conclusion after reading the first seven pages of his paper. The impression that the investigation has dealt with this problem would appear to be confirmed by the author's conclusions on the bottom of the seventh page.

> "These tests show that within the range of commercial practise there is nothing in the theory that the eye requires less illumination on the work amid dark surroundings or with dark walls than amid light surroundings with good diffusion of light. In fact quite the reverse."

The only evidence which I can find in the paper which would seem to bear out this conclusion is that afforded by the results of test 9. Since this test was made under very extreme conditions, and is not comparable with any of the other tests, it is difficult to see how it can be used to substantiate such a conclusion as that drawn. Possibly the other tests, respectively 3 and 7, and 4 and 8, which are supposed to be comparable, form

the basis of the author's conclusion. Before I saw the installations subjected to test, I assumed that with the indirect lighting system the walls were brighter than with the direct lighting system. Mr. Cravath accorded me the privilege of looking over his test conditions and I was rather surprised to find evidence that with the indirect lighting system the walls were not invariably brighter than with the direct lighting system. With doubt raised concerning this point, any conclusions from the tests must be subject to modification in so far as they are intended to show the effect of light surroundings. Incidentally, it would appear to have been obviously desirable to determine the brightness of the surroundings since a photometer was available and the making of the measurements would have been a simple procedure. It is to be regretted that this evidence, of first importance in this connection, was not included.

But even if the tests were to be found comparable, and the surroundings were to be found so much brighter with the indirect lighting system as to permit of conclusions on this point, the experiments would still fail to afford evidence for the reason that the experimenters studied a paper laid flat upon a table top under which conditions the angle of view embraced very little, if any, of the walls of the room. It is obviously impossible to study the effect of bright walls upon the eye if the eye is carefully shielded from the walls. I want to go on record as saying that after a careful perusal of the paper and an examination of the test conditions, I am unable to admit the conclusion regarding the effect of bright surroundings which the author has set forth in this paper.

In the remaining portion of the paper, the author discusses the effect of diffusion upon glare from a calendared paper. While I believe that Mr. Cravath's conclusions would have been of more scientific and practical value if the commercial element had been removed, yet I feel that he has presented a casual study, on a subject of great importance and one which many of us who are not practitioners have not properly appreciated.

The lesson of this paper as I understand it is about as follows: Where the illumination is intended to serve purposes similar to reading, it is important to secure a reasonable diffusion of the

light, either by properly subdividing the light sources or by concealing them, or by using with them diffusing glassware of some kind. For the emphasis placed upon this point by the paper, I want to extend thanks to the author, as well as to express my appreciation of the timeliness and importance of the paper.

Mr. L. B. Marks:—It seems to me that we have digressed somewhat in the discussion. The paper, as I understand it, does not pretend to say that the indirect system of illumination is the best system of lighting. I don't believe that the author would claim that, for a good many conditions in practical illumination, the indirect system of lighting would be as good as the direct. He has simply called attention to a series of tests which indicate certain results that might perhaps be considered as sequential rather than consequential.

As a consulting illuminating engineer who is interested in the design of lighting installations for all classes of work, I find valuable information in the data which have been laid before us in this paper; but I am unable from the data taken alone to come to a conclusion as to the main point raised in the paper.

Mr. Cravath with his usual initiative has made a start, in an important line of investigation, which should be followed up.

Now, in the matter of premises, the author has laid before us a number of variables, many of which do not appear to have been considered by him in setting forth his conclusions. It has occurred to me that possibly the difference in color of the lamps, the bringing them up from a very low intensity to a high intensity by rheostatic control during these tests, might have a potent influence on the results. The difference in the condition of the eyes of those who made the tests, the length of time given for the adaptation of the eye, the fact that comparative tests were made on different days, the same individuals as I understand it, being subjected to a portion of the test on one day and the remainder of the same test on another day, are points which must be considered.

As an illustration of the question of adaptation, let us take the case of a man who goes into a building that is well illuminated and has a relatively high foot-candle intensity, say 5 foot-candles, on the assumed horizontal plane, 2 feet 6 inches above

the floor; now, it will depend entirely upon the condition of the man's eye before he enters the building, as to whether he would consider that illumination sufficient or not. Under some conditions even after a period of rest he might consider the intensity too high and under others, too low; much will depend upon where he has been, upon his physical condition, mental strain, and all that sort of thing; so that these comparative figures are dangerous in a sense, unless one recognizes their limitations.

It is my purpose in discussing this matter to call attention to some of the dangers which the young illuminating engineer may encounter in considering a paper of this character. He should not be misled by what some of the numerical values therein might seem to indicate. There is a danger in making a wrong comparison between the result of the indirect illumination as carried out in this test and the result of the illumination by direct lighting as set forth. The paper is not specific enough in that it does not mention that the indirect lighting system of the latest form is compared with a direct lighting system with exposed clear glass tungsten lamps, and clear glass reflectors. These facts should have been stated, as they have a most important bearing on the question of diffusion with direct lighting systems.

I was very forcibly impressed by this particular point because the author granted me the opportunity of making a little experiment in the very room in which these tests were made. Several observers were present to compare the effect of specular reflection with the equipment described in the paper. (see tests 3 and test 4 on the twelfth page of the paper, test 3 relating to one indirect lighting fixture in the center of the room and test 4 to four direct lighting fixtures in the corners of the room). The observers I think all agreed that when the lamp equipment was the same as described in the paper and referred to in test 4, there was excessive glare from the calendared surface of the paper observed. Such glare would naturally be expected because of ordinary direct reflection of light from the bare lamps. To overcome this objection, the natural suggestion would be to diffuse the light of the units in the corners of the room; a very simple method of diffusion would be to simply cover the reflector

with a handkerchief so as to screen the effect of the direct filament, etc. I did this at the test. We had 3.6 foot-candles on the table by actual measurement, but the screening obviated practically all the glare. The lighting effect was beautiful, and each of the gentlemen, I think Mr. Cravath himself included, noted the very great difference between the results in the installation as laid out and the results with the changed installation, the only change being the securing of more diffusion,—the very thing that the author pleads for. So, I say it would have been fortunate had he gone a step further and compared the indirect lighting system with a well designed direct lighting system in which there was suitable diffusion. Those who were with us, among whom were Mr. Preston S. Millar and Mr. Ward Harrison, can also speak as to their impressions.

I will confine my further remarks to one point which I think is perhaps of as great importance as anything that has been presented in this paper, and that is that the results set forth by the author point out conclusively what we all know but what we don't seem to lay sufficient stress on, namely, that tables which set forth the intensity of illumination required for different classes of work are apt to fall far short of the truth, and are apt to be extremely misleading, unless all the conditions of the lighting installation and use of the light are set forth.

Mr. Norman Macbeth:—There is just one point which apparently has not been covered, either in the paper or in the discussion. I understand that the values given in the tables are the averages of ten readings by each observer. What was the range of these readings? Were there any high readings during the test for the "minimum comfortable" which were above the minimum values shown under the "considered ample" table. It would seem to me that a subject would be prone to settle upon a certain intensity and endeavor each time to identify that intensity by a general observation rather than through a repetition of the mental processes used in making the first determination. In both tests, under the installation conditions designated as No. 7, Mr. J. B. Jackson settled upon 0.68 foot-candles for the "minimum comfortable" intensity desired, and also the intensity "considered ample." Mr. O. H. Caldwell and Mr. S. E. Church

exhibited remarkable associations between test values in the two tables for each equipment, and I would be interested to study the association, or grouping, of the observations around the given intensity first chosen as a "minimum" or as "comfortable."

Mr. F. J. Pearson:—Too much latitude is left to the judgment of the subject as to just what illumination constitutes the quantity of light assumed to be ample for continuous reading for long periods of time, say extending over several hours. To my mind this calls for a conclusion for which a subject, who is not engaged in proof reading or similar work, is not prepared to conclusively state for the reason that no man is able unless engaged in such work, to state the limit of endurance of his eyesight. Let a man lift a weight a dozen times and then ask him how many pounds he could lift continuously for a period of several hours—do you think he could determine such weight without previous knowledge of what his muscular endurance was capable of? I think not.

Again it appears to me that each subject should be calibrated for visual acuity by some method which can be used as a comprehensive check upon any abnormal readings which may result during the test. Mr. Sweet, I believe, has developed such a method and one which appears to me as one of especial value; also some consideration should be given to subjects wearing glasses as compared with those not wearing them. I am somewhat at sea as to the value of the results shown in the tabulation of these tests shown on the twelfth page of the paper. For instance, one of the subjects compares very closely with other subjects on test 7 and 8, but varies by several hundred per cent. on No. 9. Other wide variations are so excessive that to me there appears a possibility of the presence of some important phenomena in these results as given. The results here shown are of exceeding interest and it is to be hoped that we may have more extensive investigation in this direction.

Mr. A. J. Marshall:—I think the value of any test, concerning the question of direct, indirect or semi-direct lighting, resolves itself into a matter of what we might term fatigue. To usher a person into a room such as used in Mr. Cravath's tests, which to my mind could hardly

be taken as typical of average spaces, and having him make a snap reading, and then base conclusions on such results, is hardly representative. I believe that Mr. Cravath states that the time consumed in making the test was probably between one and two hours. I accordingly assume that during this time the person under test was not seated in one position, nor was he testing only one lighting condition, but during that time he was more or less on the move, and was called upon to render decision on a number of lighting conditions, which in reality was comparable to a snap judgment, after being in the space a few moments.

The New York section of this society meets in a room that is indirectly and semi-indirectly illuminated. When, perhaps, the guests first arrive, the lighting effect is bearable. As the evening progresses, even with interesting papers, it has been my observation that there is a decided tendency on the part of the people to wink their eyes excessively, also to rub the eyes or, in some cases, attempt to shade the eyes by hands or papers. Naturally at the end of the session which usually lasts about two hours the eyes of those in attendance are quite fatigued. If we would conduct experiments at the beginning of the meeting and at the end, very widely differing results, I am quite sure, would be obtained. My idea, therefore, in investigating with a view of determining the value of different forms of lighting, is to proceed on a fatigue basis. I have been endeavoring to get together a test along these lines, and hope to get started in the early future. My contemplated method will be to take two classes of school children (disinterested parties) and make visualizing tests at the beginning of the school day, under natural light, when the vitality of the children is high, conducting a similar test later on in the morning, again at the beginning of the afternoon session, and another test about the end of the school day, constructing from such tests what might be termed fatigue curves. Then have these children meet in the same room, at the same time, within the next day or so, and after all natural light has been excluded from the room conduct test with indirect, semi-direct lighting effects. The results obtained from these two tests will, in the main, be comparable. Then take a school class

which meets at night, attended by persons who have used their eyes under various conditions during the day, and conduct tests showing the effects obtained from various artificial lighting installations.

If both the night and day classes should be composed of persons of approximately the same general age, it is probable that interesting figures would be obtained, showing not only the effect of the various systems, but the ability of the individuals to visualize when their vitality is at a high or low point. Such tests I deem very much more representative and conclusive than what might be termed "snap" test.

Mr. Cravath makes a statement which, if taken literally, would perhaps be erroneous. He speaks of glare being a matter of contrast. A literal interpretation would mean that if glare was everywhere there would not be any glare. Such, however, is not a fact. Glare is not simply a matter of intensity or contrast, although these are important factors. It is possible to have a room approximately and uniformly illuminated, even to a comparatively low degree of intensity, and have such effect give rise to glare.

I have, on several occasions, made the suggestion, and I am rather glad to say that those who perhaps are more intimately associated with indirect lighting bear me out, that if eye shades or eye protectors were supplied, indirect lighting would be a mighty good thing. As a matter of fact, I know several instances where people who were endeavoring to work under indirect lighting with ill results, became very much relieved with the use of eye shields. In the tests that were made by Mr. Cravath, it will be noted that the head was inclined forward, so that not only the eye brows, but the forehead interfered with the passage of light rays and the eye was protected.

F. L. Godinez:—It is a pleasure to hear a paper on indirect lighting which makes no attempt to represent this system as an infallible solution for all lighting ills.

Unfortunately in the East, indirect lighting has not received serious consideration by other than those directly or indirectly interested in the manufacture and distribution of its appurtenances or its publicity.

Unquestionably its promiscuous applications, in other sections of the country have been due to the radical contrast with other more conservative methods of illumination, which it affords, and in the majority of instances to the fact that the public has been surfeited with a tiresome monotony of reflector design which has served to render any innovation worth at least temporary recognition. Perhaps even a method whereby a floor area might become a luminous source under the impetus of the present day commercial methods might win favor.

On the ninth page of the paper Mr. Cravath alludes to the higher intensity of illumination required by the older participants in his test, which is of unusual interest from the physiological viewpoint. Accommodation increases the refraction of the media of the eye and adapts them to near objects causing thereby two important changes in the crystalline lens as follows: first, the anterior surface becomes more convex and approaches the cornea; and second, the posterior surface becomes slightly more convex, but remains equally distant from the cornea. That these changes actually occur may be proven by a very simple experiment. If a lighted candle is held at one side of the eye, so as to form an angle of 30 degrees with its visual axis, an observer will upon looking into the eye from a corresponding position on the other side see three images of the flame: the first straight, formed by the cornea; the second larger and upright, formed by the anterior surface of the lens, and the third, smaller and inverted, formed by the posterior surface of the lens.

This is significant with reference to the present discussion since as age advances the elasticity of the lens diminishes thus reducing the accommodation; and, the near point, gradually recedes. These changes, however, commence at a very early age, long before the individual has come to maturity. The following table indicates the amplitude of accommodations at different ages.

Years	Amplitude of accommodation dioptres
10	14
15	12
20	10
30	7
40	4.5
50	2.5
60	1.0
75	0.0

Mr. Cravath will find these values proportional, as a rule, to the illumination intensity variations identified with the age increments of his subjects of the present test.

Mr. Cravath has stated that "The subjects, with one exception, were men interested in illumination, and were selected with a view of absolute freedom from any prejudice which might be evidenced by commercial connection with any system of lighting." It would almost seem in this relation that the selection of subjects entirely ignorant of all matters pertaining to the technique of illumination might have proven advisable. The subconscious influence of the predetermined or opinionated professional mind is rather a difficult factor to cope with, and, moreover while consulting engineers are properly assumed to remain neutral even in research work which directly concerns their clients' welfare, for that very reason it would be well for them to collaborate with practising opthalmologists when dealing with problems involving abstruse physiological phenomena.

Evidently, in this instance Mr. Cravath has practically confined his analysis to a foot-candle basis of appraisement without attempting to thoroughly investigate the physiological and psychological phenomena involved.

Indirect lighting is assumed to approximate closely, natural daylight conditions, but evidently this is true only with reference to reflected flux from the plane with perhaps the sidewalks, for whoever beheld with natural light the unbalanced illumination aspect of an interior so illuminated that the ceiling affords one glaring area of high intrinsic brilliancy, giving stimuli to sections of the retina which for centuries have been unaccustomed to receive directionally such excitation?

Indirect illumination like other branches of the art, involves many divers factors demanding recognition. It is hoped that in the future these may form the basis of extensive and impartial research.

Mr. Albert Scheible:—When Mr. Cravath chose me as one of his subjects he very courteously did not say he was taking me on account of my age, although later on he called attention to it. However, as Mr. Marshall hinted, some of the differences may not have been due entirely to the age. In my

case the readings were taken on the afternoons of days on which I had been using my eyes very strenuously, and I would not consider them anywhere near normal on either occasion. However, I was not asked regarding that, and I simply went ahead and gave them the readings as they came out. I did observe, however, that ir was quite difficult to judge the point which I should consider as ample illumination or as bounteous illumination, and I question whether it is fair to go by the average man's judgment on that point. Those of you who are familiar with the European work may remember that a few years ago Dr. Graz, of St. Petersburg, made a series of tests in which he tried to determine how much of surplus light was needed for continuous work without causing fatigue; that is, determining first the intensity of illumination needed for different classes of work in order to clearly distinguish the work, and then the higher intensity needed to avoid fatigue for that class of work. His conclusion was that in order to avoid fatigue one requires twenty-five times the minimum under which one could see the work in question. Whether that reserve factor of twenty-four is correct or not I do not know, but it seemed to me in helping in these tests that it was much easier to determine the point at which we reached the distinct visualization of the type than it was to determine what I am calling ample and latter on what I would call bountiful illumination. I would, therefore, like to suggest a further possible series of tests for Mr.Cravath or some one else following up the Graz line of work so as to see if one cannot strike a basis which would not involve such an indefinite factor of judgment.

Mr. Bassett Jones, Jr. (Communicated) :—Mr. Cravath's paper is not in any sense an argument for or against indirect illumination, but is rather a description of a brief research into the effect of glare. Mr. Cravath says that "The explanation of the results obtained from these tests is to be found mainly in the matter of glare from the paper of the reading page." What should be sought for then is a method of illumination by which such glare is avoided without introducing other and equally serious defects. Mr. Cravath's argument proves nothing as to the relative merits of direct and indirect illumination, except to show that indirect lighting of the character he describes is better than

a very bad system of direct illumination. To light a room used for clerical work in the manner illustrated in tests numbers 4, 7 and 9 is barbarous in the extreme and this is not mitigated by the fact that such methods of illumination are frequently used for such purposes.

It is unfortunate that there was not included a test in which the conditions were localized lighting by properly designed desk reflectors and light surroundings, and a case in which the conditions were low general illumination obtained by indirect or semi-indirect methods with properly arranged local lighting of higher intensity. If such tests had been made I believe that the conclusions reached would have been modified. Comparisons should not be drawn between an archaic method of lighting such as that used in test No. 9, where a simple drop cord was used, and the carefully designed arrangement used in test No. 8. Such comparisons can prove nothing useful and may be very misleading.

The lighting of rooms such as banking rooms in which a large amount of clerical work is done deserves very careful study. The conditions vary widely with the room and cannot be met by generalized methods. It is not always wise to use only indirect illumination; indeed I doubt if it is ever wise. Nor is it always wise to use direct methods. A combination of the two methods in which the proportion of direct or indirect varies with the conditions has solved many problems, and I believe will in time become the accepted method of meeting such problems.

An illustration may be drawn from a case that recently came under the writer's notice. In one of the large banks in New York a room, poorly provided with natural light, is used for close clerical work where trial balances are, as usual, made with fine hard pencils so that the footings when checked may be filled in in ink. The clerks sit at high desks against the four walls, the center of the room being occupied by large tables on which the ledgers are piled and sorted. Ordinary fixtures with prismatic reflectors were used in the center of the room, and drop cords equipped with metal cone reflectors were used to light the clerks' desks, one to each clerk. The ceiling of the room was white, more or less toned down by dirt. The walls were light buff. The

furniture was oak with a dead finish. In order to avoid the glare of which Mr. Cravath speaks the clerks had generally provided paper curtains and paper bottoms for their drop light shades. It was assumed therefore that the entire method of lighting was wrong, and instead of trying to improve the existing method by changing the details of the equipment, the authorities installed a system of indirect lighting differing in some of its details from that described by Mr. Cravath. The old drop cords were left, however, but the clerks were instructed not to use them. This was the condition of affairs when the writer was asked to look things over.

On entering the room the writer noticed that many of the clerks hurriedly reached to the old drop cord fixtures which had been set with the aperture of the cone resting on a shelf over the book racks at the back of the desks. When the clerks understood that the writer was not there to spy on them, they told him that it was not possible for them to see their pencil footings unless they got some direct light on their books from the drop cords, to do which they turned on these lights and surreptitiously slid them over the shelf until a portion of the aperture was exposed. Yet the room was quite brightly lighted. They complained of the lack of decisive shadows which under the old conditions, enabled them to properly locate the pencil point by the converging lines of the lead itself and its shadow.

The writer recommended a method of meeting these conditions that he has used with success in similar cases, namely, to provide a low general semi-indirect illumination, just enough to prevent excessive contrast and to provide enough diffuse light so that the ledgers on the center table need not be turned upon edge to read their titles, and a properly designed trough reflector unit supported from the desk shelf so arranged that no direct light from the reflector or light directly reflected from the desk surface, or from papers laid upon it, could reach the eye.

By thus reducing the general illumination over large areas, and properly increasing the illumination over small areas where higher intensities are needed, the total flux required will be a minimum. Glare is avoided by proper reflector designs, and the neces-

sary shadows, which are guides to the eye, are preserved and made luminous by the general diffuse light.

This matter of the proper proportion of diffuse to directed light is of primary importance. Mr. Cravath speaks of the importance of diffuse light similar in character to daylight, but as Dr. Ives will show you in his interesting paper, daylight is not diffused. In fact its characteristic curve closely resembles that of a focusing reflector. It is sharply directed, the diffusion being but a small proportion of the whole. And this directed daylight is still more emphasized in the case of interiors lighted by windows. One even takes pains to arrange his furniture and desks with relation to the direction from which the light comes. If then one is to work under the same conditions by artificial light as he does by daylight he should have surface sources arranged as nearly as possible in the position of the windows.

Mr. J. R. Cravath (in reply):—A previous speaker has said in effect that the values in this paper are only generally indicative and that they do not settle many of the finer points. I fully agree with him on that. The whole general scheme of the tests was rough, yet the variations that were found during the test were considerably less than one would anticipate in a test of that kind.

Mr. Sweet's chief fault found with the conclusions, (and that is true of several of the other speakers who followed him) seems to be that I did not separate the factor of dark surroundings from the factor of unidirectional light. I am perfectly willing to admit that it would be desirable to separate those factors and also some of the other variables that come in, but what all these gentlemen seemed to have lost sight of is the fact that diffusion and dark surroundings don't go together commercially and never under any of our ordinary arrangements. Now, if one is bound to have poor diffusion with dark surroundings he is not particularly interested, as a commercial engineering proposition, in what might happen if there was good diffusion with dark surroundings. That information would nevertheless be of academic interest and probably of future practical value. In other words, one does not care so much how or of what elements the total result is made up, as what the total is. One finds in one case

of extremely diffuse conditions of lighting that one set of results was obtained and in another case, under an extremely unidirectional system of lighting, another set of results which varied decisively from the first was obtained. There is only one conclusion to draw. As to the intermediate conditions the results are as I have already said, indecisive, but nevertheless valuable as indicating that indirect lighting requires no higher illumination for satisfactory work than does direct.

Mr. Marshall brought up the point that fatigue is probably an element that we ought to reckon with and I fully agree with him on that: in fact, I was looking for it to some extent during those tests; that is, I anticipated that possibly a subject when starting on a test fresh would require a different degree of illumination from what he would at the close. Sitting, under test, from an hour and a half or two hours a man was naturally looking at the paper intently a part of the time and I anticipated a certain amount of fatigue. However, I was unable from the results to draw any conclusion from that one way or the other. Some subjects apparently required more illumination as they continued under the test; while others required a little less. I think it would interest members to know the methods that Mr. Marshall proposes to use on his acuity tests with school children and I hope he will communicate them to us in due time.

Another statement made by Mr. Marshall as I understand it, is that the glare effect depends on the area, from which the light comes. We must assume an equal foot-candle intensity entering the eye in two given cases, in order to make the comparison. Now, according to Mr. Marshall's line of reasoning a certain number of foot-candles delivered from one square foot of illuminated surface would cause less annoyance than the same number of foot-candles delivered from say a hundred square feet, which is preposterous on the face of it.

Mr. A. J. Marshall:—Just the reverse, Mr. Cravath.

Mr. J. R. Cravath:—You meant to say that the glare is reduced the larger the area the illumination is received from?

Mr. A. J. Marshall:—No.

Mr. J. R. Cravath:—Then my first line of reasoning stands.

Dr. Cobb gave a very simple illustration in his Baltimore lecture[1] as to the relative effects of equal flux of light received from large surfaces as compared with small surfaces. In fact, in connection with this matter of the size of surfaces from which light is received I have been considerably amused, gentlemen, with the turn discussions have taken recently when the question of direct and indirect lighting has come up. Members of the Illuminating Engineering Society have all been agreed ever since this society started that bare light sources right in the field of vision are a bad thing and that we should make an effort to increase the area from which we are receiving our light by the use of diffusing glass. Things went very well until finally some of us said let us go a step further. Instead of putting diffusing globes and lanterns and things of that kind over a source of light let us send the light up to some diffusing surface and get it back again by reflection. As soon as we got to that point a number of gentlemen immediately apparently changed their ideas as to what is the desirable end to attain. That includes my good friend Mr. Marks. Mr. Marks is as much a stickler for the absence of glare within the range of vision and the shielding of bare light sources, and that kind of thing, as I am, but he simply stops a little sooner than I do in applying the logical remedy.

I can not take seriously Mr. Marshall's statement about the eye shades necessary when light is received indirectly from ceiling areas with the indirect system. That statement is too obviously humorous.

Mr. Scheible questions the average man's constancy of judgment as to the amount of illumination required for a given piece of work, and probably he is right. The public is the court of last resort, and it is well for us to find out what the different members of the public really require or think they require, because they are the ones who must be suited.

Mr. Macbeth asks as to the percentage of the variation above and below average in the illumination required by the different subjects. On looking up those figures I find that most readings were within twenty-five per cent. A very few of them were in

[1] Lectures on Illuminating Engineering, Johns Hopkins Press, Baltimore, vol. 2, p. [illegible]

excess of thirty per cent. variation from the average. Most of the subjects seemed to have a fairly definite idea of what they wanted as to quantity. I was surprised at the uniformity. I had no idea they would come so close.

Mr. Godinez refers to the high intrinsic brilliancy of ceilings with the indirect lighting. In exact statements of that kind made carelessly in our proceedings tend to lower the general standing of the society. If we don't get the respect we ought to outside it is partly because of such careless statements appearing. With an equal number of foot-candles on the working plane, the larger area of the light sources the less the intrinsic brilliancy. Now, the intrinsic brilliancy in candle-power per square inch of a ceiling with indirect lighting is probably not over a thousandth of what it would be with any ordinary direct lighting system. Now, when one calls a ceiling under those conditions a ceiling with "high intrinsic brilliancy" I maintain that it is an absolutely absurd statement.

Mr. Marks remarked on the color differences perhaps making a difference in my tests, and I have felt all along that perhaps that might have some influence. I tried roughly to eliminate that factor as far as possible and to have the color as nearly the same as possible with the different tests. However, it may have had some influence. The indirect light was more yellow than the direct light. Mr. Marks described the little test that we made the other day by reducing the glare from the work by simply hanging some handkerchiefs over the direct lighting units, thus cutting down materially the percentage of direct light. I was very glad he mentioned that. He failed to mention, however, the loss in efficiency which occurred by that change. In fact, the loss of efficiency he brought about by that simple procedure brought the efficiency of the direct lighting system far below what the indirect would have been. While I agree with him it is perfectly possible to produce good diffusion in the way he did, it is more economical to do it the other way and get the light by reflection from the ceiling.

Mr. Marks in his Baltimore lecture[1] last year commented on some things which illustrate the point I am trying to bring out

[1] Lectures on Illuminating Engineering (Johns Hopkins Univ. Press) vol 2, p. 648.

in this paper. I refer to his remarks on the South Shore Country Club ball room here which has an installation of indirect lighting with red walls, and light ceilings. Mr. Marks visited that installation one evening when the floor covering was dark. It is ordinarily used as a ball room and has light colored floor, but when it is used for an assembly room they put a dark canvas covering on the floor. The results in that room when the dark floor covering is on with the dark walls is a striking illustration of the necessity for diffusion—the very thing I am trying to bring out in my paper. The vertical illumination is so low—because of dark walls and floor—under the conditions under which Mr. Marks saw it that the faces of the people that are in the room appear relatively dark. It is comfortable illumination but it is not sufficiently diffuse for illuminating the faces of persons in in the room perfectly. The difficulty is entirely done away with as soon as the dark floor covering is removed. It simply proves my point of the necessity for diffusion. If that room had light colored walls there would be no trouble about diffusion under any floor conditions.

Mr. Millar is quite right when he says I changed my mind after I got part way through with my series of tests, as to what were the relatively important things to look for. I started out with the idea that light or dark surroundings would have a big influence on the amount of light required. Mr. Millar's tests pointed that way: in fact, they conclusively proved it to my mind as far as the conditions were concerned. When nearly through the tests I saw that the effect of undirectional light was so much greater than the effect of the surroundings that diffusion was the main thing to consider under commercial conditions. But Mr. Millar apparently loses sight of the fact that diffusion and dark surroundings don't go together.

Mr. Jones gives an interesting account of a case in New York where direct and indirect was tried in an accounting room, but since he gives no figures on foot-candle values on the working plane under the different conditions, his discussion is absolutely of no value. It would seem to me quite possible from the description which he gives that the clerks were actually working in their own shadows with the indirect light and didn't know it.

Now, with direct light there are shadows, (many previous statements to the contrary notwithstanding) and they are very much like daylight shadows; they merge gradually from the middle out to the edges. With such a very gradual transition in illumination from the centre to the edge of the shadow it is quite possible under the indirect system that the illumination is not quite sufficient in the shadow, yet the worker does not realize it. One may not realize that there is any shadow there. It was quite evident in this case that the illumination was insufficient in quantity because Mr. Jones states they could not see the pencil marks, and could not see to work because they did not have the shadow of the pencil. It is quite evident they didn't recognize any shadow, and yet with the indirect light in the center and the clerks working around the sides, in that case they were undoubtedly working in their own light. In such cases there should be sufficient illumination provided under any kind of system so that they would get enough illumination in the most dense part of the shadow.

I am very glad that most of the previous speakers agree on one thing that I have directed more attention to the importance of diffusion. I have always had an idea that it was important but I never had an idea it was so important until I began to conduct these tests. I think if you gentlemen will study it more you will see it is a much bigger element than you have heretofore considered it to be in satisfactory lighting. There is nothing more comfortable to read with than daylight out in the open on a very cloudy day. If you have never tried it go out and investigate it some time. With rather heavy clouds the diffusion is very perfect. It is the most comfortable light that I have ever found for reading on a glazed paper.

Mr. Bassett Jones, Jr. (Communicated):—In reply to Mr. Cravath's remarks regarding my contribution to the discussion, I can only advance the thesis that the eye and not the photometer is the only and proper judge of the correctness of illumination. By correctness I do not mean close correspondence with any preconceived or calculated values of intensity, but that the system as laid out does in a measure meet the demands of the eye and is an agent whereby the eye is enabled to properly fulfill its

functions. All illuminating schemes must therefore be developed experimentally. The only value of a knowledge of foot-candle intensities is to enable one to duplicate such successful arrangements and to enable one to in a measure remove the experimental factors.

If a scheme of illumination is wrong, in this sense, then readings of foot-candle intensities are generally useless and the time required to take them wasted.

In the case cited in my discussion the illumination being obviously wrong, and the light improperly distributed, the most obvious step was to correct it. Then, having corrected it, readings made under the revised conditions might be of value for future use should a new problem arise in which the conditions reasonably approached the same working conditions. It is rarely that two problems of this kind bear much similarity to one another.

Of course I do not decry the gathering of such data as Mr. Cravath mentions when time is available. But I do insist that too much so-called illuminating engineering is done in just this way, by trying to standardize intensities when, as a matter of fact any such standardization is offset by the multitude of variables that enter into the problems. The sum total of the effect of these variables is generally greater than the effect of the one or two constant factors.

To revert to the problem cited, it is only necessary to say that the clerks were not working in their own shadows. As a matter of fact the intensities in various directions on "the working plane" were, so far as the eye could detect, equally balanced. Furthermore the complaint was not with regard to the quantity of light, which, again so far as the eye could judge, was ample.

But in order to produce this result as to quantity too much flux was wasted lighting dirty ceilings and dirty walls.

THE ANALYSIS OF PERFORMANCE AND COST DATA IN ILLUMINATING ENGINEERING.[1]

BY WARD HARRISON AND H. H. MAGDSICK.

This paper is presented with the hope that it may aid the man interested directly in the application of light sources in making a thorough and logical analysis of the performance of available units, and further that it may lead to the publication of a large amount of reliable data, which is necessary for such analysis.

The papers that have been presented before the society during the past few years may, in general, be divided into three classes. The first includes those dealing with the basic principles of illumination, photometry and the allied branches of science, and the theoretical considerations involved. The second group takes up the manufacture of various illuminants and a description of their mechanical details and operation. The third group deals mainly with a description of installations and with reports on illumination tests. Between the second and third groups there remains a field which, although it is perhaps of the greatest interest to the man engaged in the practise of illuminating engineering, has scarcely been touched upon in the papers presented; that is, a study of commercial light sources as such.

The conditions which must be met in order to obtain satisfactory lighting are relatively well understood, but there are few men who have more than a very general knowledge of the actual service performance and operating cost of the units at their disposal. Much data is available from which the illuminating engineer may determine with a considerable degree of accuracy what initial intensity he will obtain from a given installation, but to calculate the initial illumination to a high degree of accuracy when the average performance in service is oftentimes not known within twenty-five to fifty per cent., seems an unnecessary refinement; and only too frequently no allowance is made for such depreciation when an installation is planned.

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

The small manufacturer or business man is not warranted in assuming the expense of extensive tests which would satisfy him as to the relative merits of two illuminants, but at this time there seems to be no other way in which he may obtain information of the reliability of which he has any assurance. The mass of conflicting data furnished by the manufacturers of the various lighting units naturally arouses in him a certain suspicion of all such information. Several large corporations have undertaken elaborate investigations of the comparative merits of different light sources for their particular classes of work. Anyone who has attempted to go into this subject thoroughly realizes what a mass of evidence must be secured and how much money must be expended to obtain even a small amount of conclusive data. It is not surprising, then, that some of these tests have not lead to satisfactory results. In any case, if each manufacturer or each corporation is compelled to undertake its own investigation, there results a useless duplication of material, which is extremely wasteful.

If this data could in some manner be brought together, tabulated in systematic form and subjected to the criticism of engineers capable to pass upon its worth, it would be of inestimable value to illuminating engineers. This is a matter of vital interest to a majority of the members of the society and it seems highly desirable that papers upon this branch of the subject should more frequently find a place in the TRANSACTIONS. The authors realize that it is no small task to bring together the data now available and that it is difficult to set up equitable standards of comparison; however, through cooperation among the members, the material could in due time be put into useful form. If the manufacturers of the various commercial illuminants were invited to prepare papers on their respective products, contributing complete performance and cost data, this material would doubtless be augmented by the experience of illuminating engineers and consumers, and a fund of information would be provided upon which a man engaged in the practise of illuminating engineering might draw with a feeling of security—data which would bear the stamp of impartiality and reliability as engineering information rather than advertising material.

Few seem to realize the importance of including in an analysis

all factors which determine the relative value of illuminants; at any rate, one seldom finds a comparison which is thorough and complete; and this is true in spite of the fact that the considerations involved are of an elementary nature. Doubtless some of them are difficult of exact statement; nevertheless they require careful attention. Certain of these considerations the authors regard as essential in forming a satisfactory judgment of the value of lighting units, and, while they may not be entirely comprehensive, they have been found of great assistance in work of this character. The more important items may be grouped under two heads; first, illuminating power, and second, cost.

In determining illuminating power it is important to consider the total flux from the unit, both the initial and the average, during the life of the renewal parts in the laboratory and under service conditions; the utilization of this flux as determined by the size of the unit, the distribution secured and general adaptability to the given conditions; also, the quality of the light, its steadiness, and diffusion.

The mean spherical candle-power or total light flux is, of course, the fundamental basis of comparison, and this should be obtained for each lamp with the various types of standard equipment. The initial flux and the average during the life of the renewal element relate, as a rule, to laboratory performance. All illuminants show an inherent candle-power depreciation under the best conditions. In service, the performance of the unit is further impaired by variables which can be controlled in the laboratory but not under practical operating conditions. The subject of average intensities was discussed in a recent paper by Mr. S. W. Ashe.[1] The question of the effect of dust and dirt, which sometimes cause a large part of the service depreciation, has never been given the attention it deserves. There is an opportunity for valuable work in determining the shape of the depreciation curve and the intervals at which lighting units should be cleaned to secure the highest economy.

The utilization factor, or the ratio of useful flux to total flux, has been determined for certain conditions in the case of some illuminants. As a rule, however, the mean intensity of the units, the type of reflectors available and the distribution which

[1] *Trans. Illg. Eng. Soc.*, vol. 6, p. 496.

may be obtained, the possible spacings and heights of suspension, and uniformity of illumination must be considered in each individual case.

Up to this point the value of a unit may be closely approximated. While it is desirable to establish these standards of measurement, it should be remembered that they do not form the only criteria: the determining factor may be one of several additional considerations, the effect of which can not be stated in exact terms. It is not enough, for example, to take into account merely the average intensity of a fluctuating light source. On the other hand, diffusion or glare may decide the value of the unit, depending upon the class of work to which it is applied. What weight should be given these matters may well be left in each case to the judgment of the illuminating engineer.

The discrepancies which are so common in cost data may be largely eliminated by a careful analysis. In determining the total operating cost of any system of lighting, three items should be considered:

(*a*) Fixed charges, which include interest on the investment, insurance and taxes, depreciation of permanent parts, regular attendance, and other expenses which are independent of the number of hours of use.

(*b*) Maintenance charges, which include renewal of parts, labor, and all costs, except the cost of energy, which depend upon the hours of burning.

(*c*) The cost of energy, which depends upon the hours of burning and the rate charged.

If data are compiled under these heads in convenient units, such as in (*a*) an annual charge, in (*b*) a charge per 1,000 hours operation, and in (*c*) a charge per 1,000 hours operation at unit cost of energy, the several items may easily be calculated for any given set of conditions and the total annual operating cost of any lighting system obtained as their sum.

Under fixed charges, the items of depreciation and attendance may be mentioned particularly. Depreciation should be charged on permanent parts only, and not upon parts the renewal of which is provided for in the maintenance cost. The rate for depreciation should in many cases be higher than the current practise, for obsolescence, rather than the wearing out of parts, de-

termines the life of a lighting system. There are many installations in use to-day which are in good order and giving a fair measure of satisfaction, but which could be replaced at a large saving.

Too much emphasis can not be given to the desirability of regular attendance for those illuminants which do not require trimming from time to time. It is essential for satisfactory operation that such lamps and reflectors be cleaned at regular intervals, hence a fixed charge should always be included for this service. Lamps which require frequent trimming are cleaned at the same time, and the cost is included under the maintenance charge.

The energy cost can usually be readily computed but will, in the case of some electric illuminants, depend upon the voltage of the circuit, since this determines either the wattage or the power-factor. The effect of power-factor is seldom considered although it governs the investment in generators, transformers, and wiring, and in a small degree, the energy required. To the central station or isolated plant, the volt-amperes required by a given lamp are perhaps as close a measure of the cost of service as the actual wattage consumed. When the consumer is purchasing energy on a kilowatt-hour basis this factor, of course, is eliminated so far as he is concerned.

Aside from the items which may be classified under illuminating power and cost, there are certain features which the illuminating engineer must recognize in selecting a lighting unit. As examples of these may be mentioned the operation on fluctuating voltage or pressure, the possibility of protecting the units and circuit against over voltage, the likelihood of outages and their influence on production, the general effect of the illumination, and the adaptability to artistic treatment.

The value of an illuminant can not, then, be measured wholly by arbitrary standards; certain factors must always be considered in their relation to the individual installation. However, the establishment of equitable standards, so far as possible, and the compilation of data on commercial light sources in accordance with these standards is a work which, when accomplished, will be of positive benefit both to the consumer and to the illuminating engineer.

DISCUSSION.

Mr. Norman Macbeth:—I would agree with much of the thought expressed in this paper if the authors had only called it by another name and had omitted those parts which clearly fixed their desire to have placed on record the "comparative merits of different light sources." Otherwise there is much that is good in the paper. As it now stands, however, I would consider it to be somewhat of a millennium paper. We cannot overlook the situation which has been much in evidence at this convention—that we have commercial interests whose finger never leaves the pulse of this society. By some this has been considered desirable, although I believe it will be admitted that on this point there is an opportunity for a difference of opinion. The kind of information desired, if I read the paper correctly, will not add to the usefulness nor to the harmony of our meetings. This is not a declared commercial organization nor one having privileges which a strictly commercial association could not countenance; and to place the endorsement of this society on the results of "a study of commercial light sources as such with conclusions which could be used to satisfy the business man as to the relative merits of two illuminants, is treading upon exceedingly thin ice, or in the parlance of the aviator "upon a hole in the air". Such a policy is rendered still more impracticable when we realize that such information would find its greatest use in the hands of rival salesmen who would be quite prone to distort, to state it mildly, the data thus available to the uplifting of their own particular product over that of their competitor.

There are a number of good reasons why the main thought in this paper should not be carried further. The result of the investigations, outlined by the authors, finally bearing "the stamp of impartiality and reliability as engineering information rather than advertising material" would not in my opinion be constructive but destructive.

The constructive work so far to our credit is so comparatively small, that we should not, at this time, consider any line of effort which will not tend to cooperate, and upbuild all interests identified with the entire field of useful endeavor.

The undeveloped field is so large and the installation require-

ments are so varied in character and have been investigated to such a slight extent, that we should not hope to cast all to the same mold, even should we overcome the personal factor of the architect and the consumer whom we have always with us, and without whom there would be no occasion for this society.

On the other hand, if we admit it is desirable that we have reliable data on all the sources available for use, where are we going to get two or three men with the experience, the reliability, the impartiality and freedom from commercial influences, to properly edit the data submitted, not only to the satisfaction of those who propose to use it, but also to the man who presented the material for editing. Of the difficulties which would be presented we have had illustrations in a small way in this meeting: untrue inferences have been drawn; writers and some of those contributing to the discussion have been subject to, or have aided in cross examination, to inference and evasion, and for what?—not always to get the truth, but rather to confuse and embarrass another member or to prevent being exposed after having submitted pure advertising matter under the cloak of engineering data. The recognition of this spirit is not sufficient, it must be overcome before we can seriously consider "laying all of the cards on the table."

If we grant the statement on the second page of the paper that "the small manufacturer, or business man wants to know the relative merits of two illuminants", may this society furnish that information? I cannot see the justification, any more than we could advance the claims of a consulting engineer, who regardless of engineering ethics, would solicit the aid afforded by this society's endorsement in seeking clients in competition with other engineers who may not be enrolled upon its membership list.

If we confine our efforts to helping along the cause of illumination in a broad-minded unselfish manner, considering each situation or problem from the scientific rather than the commercial standpoint we will clear the commercial personal preference rocks, which are so near the surface and with which the route over which we have passed in the last five years has been so thickly strewn.

This society cannot be successful if the transactions are largely

devoted to advertising matter or to the exploiting of labels or trade names of lamps, reflectors, or other accessories, whose chief claim to recognition may be that the exploiter was one of those volunteers who so gladly put their shoulders to the wheel when the society was younger and unable to walk alone. If the present advertising methods are worth while to those benefiting thereby, what would be the market value of the society's endorsement of a commercial light source on the basis of its ultimate value as an illuminant? — undoubtedly of inestimable value, provided the society survived the experience.

There is yet a great deal of valuable work to be done in the third group mentioned on the first page of the paper dealing with descriptions of installations and with reports on illumination tests. This field has been but slightly investigated and to a lesser extent have papers on that subject appeared in the TRANSACTIONS. The encouragement of these papers will broaden, rather than narrow the scope of this society. We require a still greater variety of light sources and accessories—a multiplication of our special sources, to better meet the peculiar requirements of many installations—and not a reduction of a few sources now available, which would undoubtedly result if the thought expressed in this paper was acted upon. To eliminate the inefficient or unsatisfactory sources by an endorsement of the favored equipment could only be possible by choosing arbitrary methods of comparison which cannot possibly take into consideration the installation requirements. We do not know to-day what these requirements are, and there is an enormous amount of work to be done before we will add appreciably or at all conclusively to our present knowledge of the subject. To take up "a study of commercial light sources as such" would be, in my opinion, a waste of time, excepting for those manufacturers whose product must climb up over that of a less wide awake competitor, a condition in which as a society we can have no possible interest.

Let us have more contributions on the study of installations, of the requirements for illumination and the means which were used to meet them. Let us insist that the member contributing a paper purporting to be an analysis of an installation, include that which the authors state has been lacking in some papers now in the

TRANSACTIONS "all factors which determine the relative value of illuminants"; when "the considerations involved are of an elementary nature", but which by their omission result only in adding to the pages of the year's proceedings rather than to their value as a book of reference.

In reporting on the costs, as outlined by the authors, I can agree with the method of using three headings as stated, with the exception that regular attendance should not come under fixed charges "A" but under the maintenance charge heading "B." Regular attendance has been very difficult to settle upon and is more frequently irregular. One important factor on which we have been trying to convince consumers, is the advisability of cleaning lamps and reflectors, and I have been unable to find any establishment where regular periods have settled upon. In fact, with one large concern where they have an extensive maintenance system, they have not as yet in the course of a year and a half determined the periods at which certain equipment should be cleaned. The entire equipment is inspected daily for burn-outs, and tests have been made from time to time in the endeavor to determine just what condition a reflector should be in, that the loss in illumination will not exceed the cost of cleaning the glassware and putting it into first-class condition again. At any rate I can see no harm, if there is any possible question on this item, in bringing these charges under class B. It would certainly be undesirable under the above circumstances, to have them considered under class A heading.

Mr. R. B. Hussey:—The energy cost based on the given number of hours of burning is an important item but is perhaps the most variable of all. The rate per kilowatt-hour must be assumed and as this varies greatly in different places and under different conditions the cost of energy can be only approximate, unless the particular conditions are known. By keeping a uniform assumed rate, however, a fair general comparison can be readily made between different units or systems. The other items mentioned such as renewal of lamps and electrodes, labor, etc., equally dependent on the hours of burning, are more easily approximated and do not vary as much in different places.

The fixed charges are most easily compiled on the basis of a

year's burning, and in general comparisons of street lighting equipments I have usually figured on the all night every night basis which amounts to about four thousand hours per year, instead of figuring on one thousand hours. It makes it somewhat simpler to figure the maintenance and energy on the basis of the complete year so as to compare more directly with the fixed charges that are made on the basis of a year.

I note that the question of power factor has been raised by the author. I believe it is quite essential and in general I have figured the energy as volt-amperes so as to include this relation. Another point in this connection when comparing different kinds of systems, is to include the initial or average efficiency of the unit in terms of the cost of maintenance for a given quantity of light or illumination. This gives a more complete figure in the comparison of different kinds of lighting systems.

Mr. L. B. Eichengreen:—In the laboratory with which I am connected we have realized the fact that depreciation in candle-power does occur with lamps of all kinds and glassware; and in order to take care of this we simulate the service conditions as closely as possible in order to give the man who is to use the illumination data, figures which he really can work on. I think that a fair figure for deterioration would be fifty per cent.; in fact, we use that in our calculations. I might also say that I don't think that the average illuminating value, the average flux from the unit, is the thing to use. I think that the minimum value ought to be used in all cases.

Mr. Ward Harrison:—I just want to ask whether this speaker meant to suggest a general factor of depreciation of fifty per cent. for all lamps or for only certain types?

Mr. L. B. Eichengreen:—In this I am alluding only to gas lamps, but we would use the same figures for electric lamps or any other illuminants.

Mr. G. H. Stickney:—This paper is particularly interesting in indicating the best method of comparing the performance and cost of illuminants. While it is possible that the data now available will not permit fair comparisons of all illuminants on this basis, it is certainly the end to be desired and the one toward which we should all work. Personally, I am optimistic and

believe that the advantage of obtaining and publishing honest and accurate data is becoming more and more thoroughly realized by the manufacturers of illuminants, and when this is supplemented by the data which large users of light are accumulating, a fair comparison is certainly possible. I have in mind the thorough and complete tests which a large steel corporation is making to determine the true value of illuminants for their conditions. When this data becomes available, by modifying it to suit other conditions we will have the advantage of data which must be free from bias.

In the discussion, it has been suggested that a fixed depreciation factor for candle-power performance is desirable. This seems to be impracticable, since some illuminants inherently depreciate more than others, while in some classes of installations, depreciation from accumulation of dust, etc., is greater than in others. In giving the lighting performance it will be necessary to show it in several different ways; that is to say, in some instances the total flux produced will be the most useful comparison and in others, the downward flux or flux below the horizontal. Beyond this, the flux or intensity through different ranges of elevation becomes important for different classes of problems, and right here we are in need of further experience to determine the relative value of light at different angles of elevation for different classes of lighting installations.

The authors have separated the cost of light under three headings; namely, fixed charges, energy and maintenance. It has been suggested in the discussion that certain charges might preferably be transferred from one of these items to the other. I have frequently found it difficult to determine, for certain charges, just where they can best be classified. With certain classes of illuminants or certain classes of installations some charges seem to belong naturally in fixed charges, while in other cases the same charges can more accurately be considered under maintenance. It will probably be necessary to maintain a certain flexibility in classifying items, simply keeping under fixed charges those items which vary with the time of installation, independent of the hours of burning, and classifying under maintenance all those items depending upon the hours of burning, except those de-

pendent upon the price of power. The object of keeping the energy separate from the maintenance is to make the method more readily applicable for translation from one price for power to another. In some cases I have found it desirable to divide the maintenance under two separate heads in order to facilitate the application of the calculations for different variations of conditions. I believe this attitude is the same as that taken by the authors of the paper.

Mr. R. F. Pierce:—I quite agree with what has been said by the authors of the paper, and those who have discussed it, regarding the importance of data on economy in lighting apparatus. It seems to me that the proper activity of the engineer has to do almost entirely with economy. You will remember the definition of engineering given by Sir Mark Brunel, "An engineer is a man who can do for one shilling what any damn fool can do for two." That of course is considerably exaggerated, but what I wish to draw attention to is this: that in so far as the illuminating engineer has to do with artistic considerations he is outside of the strict field of illuminating engineering; and while this discursion is rendered necessary by commercial conditions at present, the fact remains that an illuminating engineer as an engineer has chiefly to do with economy.

Regarding the absence of exhaustive data regarding the performance of units other than electric units, especially the absence of factors for correction from other standard conditions, I realize and will admit that there is an insufficiency of such data, but that is not due to any indisposition of the manufacturers of gas lighting apparatus to submit such data, but rather to the difficulty of separating the various factors which go to make up depreciation and discrepancies. These difficulties are considerable and the data is not obtainable at present. The gas people should be very glad to present such data if they were available.

Regarding Mr. Eichengreen's statement of a depreciation factor of fifty per cent. being allowed for gas lamps, I would like to enquire what factors go to make up that fifty per cent. depreciation figure and in what proportions; how much is assignable to depreciation of mantles; what kind of mantles; how much is due to depreciation of glassware; and how much is due

to other causes, whatever they may be. It is highly necessary that all factors entering into depreciation be definitely understood and I think that further discussion of that is very essential before fixing any factor for depreciation whatever.

Mr. L. B. Eichengreen:—I wish to add that the fifty per cent. depreciation figure that I just named is not the figure which is obtained in the laboratory. It is the figure which is in use in selling service to the consumer when the lamps are not on maintenance. We assume that we want the consumer to have the correct service throughout the entire life of the unit and therefore we assume fifty per cent. depreciation. One of the severest tests which we gave a gas lamp was to install it in a kitchen under a hood where it collected the dirt and grease. This lamp burned for a period of about five hundred hours. In that time there was a depreciation of 29 per cent. After cleaning the globe, the glassware, the depreciation was six per cent. I might cite another instance where an indirect reflector was used for one year without cleaning. In this instance there was a depreciation of fifty per cent.; but upon cleaning the reflector, the depreciation amounted to only about 5 per cent.

Mr. R. F. Pierce:—It is obvious from Mr. Eichengreen's reply to my question regarding the method of evaluating the factor of the depreciation which he mentioned that it is really a factor of safety rather than a factor of depreciation or a discrepancy factor between laboratory and service conditions. It really represents the effects of a maximum amount of abuse by the user combined with the effects of the poorest service and maintenance conditions. Under such circumstances a factor nearly, if not quite as large, should be applied in design of the illumination by any illuminant if the engineer is to be assured that results at least equal to the calculation are to be obtained.

Gas and electric lighting units differ in this particular in practise: Gas lamps are affected to a greater degree from abuse by the user, while electric lamps are affected to a greater degree by variations from normal service conditions. The assigning of a factor of safety depends more upon the engineer than upon the illuminant.

Gas lighting engineers are naturally more conservative than

electric lighting engineers for the good and sufficient reason that they can afford to be. The inherent economy of the illuminant enables them to use a greater factor of safety. This largely accounts for the fact that higher degrees of illumination prevail with gas lighting than with electric lighting. Having provided a higher factor of safety, only a small portion of which is absorbed in practise, calculated results are quite generally acceded.

It is a significant fact that as far as recent contributions on the comparison of illuminants are concerned, no factor of safety whatever has been allowed with, or mentioned with reference to electric lamps. Such a practise can never by any stretch of the imagination be considered good engineering. If we consider the fact that users of tungsten lamps are prone to operate them at the bottom rather than top voltage; that circuit voltages may be, and very often are, considerably below the rated voltage; that considerable voltage fluctuations occur, and that excessive line drop is by no means uncommon, it will be seen that a designer who anticipates equaling calculated results under a combination of the worst of all these factors, must use a factor of safety of about 50 per cent.

The operation of a tungsten lamp at bottom voltage would reduce the candle-power about 10 per cent. below the rated candle-power, and operation at 10 per cent. below normal voltage would entail a further reduction of 30 per cent., leaving only 10 per cent. for the effects of dirty glassware, etc.

The fact that gas lighting engineers use a factor for safety so much in excess of that of common electric practise, indicates not a greater discrepancy in the performance of the gas lamp in practise as referred to laboratory conditions, but a desire to avoid overrating the illuminant, and obtain results which may be relied upon to equal the calculations under the worst practical conditions.

Mr. J. R. Cravath:—Mr. Eichengreen dropped one remark which interested me because I have given some thought to it, and that is the question of minimum value. When and where one must apply minimum values in performance data? For example, one instance which comes up most prominently in an arc light for street lighting purposes. It is a serious question

whether a lamp which is fluctuating violently from one moment to the other should not be rated on its average value but rather on its minimum value. I have no doubt that the incandescent lighting people would be very glad to see arc lamps rated on that basis, but seriously that point must be considered. The effect of contrast in the illumination from one minute to another with a fluctuating lamp is a strong detriment to the fluctuating lamp, and an illuminant the average performance of which might be considerably lower but which is steady might be a better illuminant for the purpose. I simply wish to call your attention to that general principle hoping that it may be considered more in the future.

Another instance where the minimum value figure ought to be considered is in the lighting of large areas, such as stores and general offices, where there must be a certain minimum illumination in all working parts of the room. It is not sufficient to have a high average intensity. There may be places where the intensity will be far more than is needed, but nevertheless there must be a minimum for the requirements. One is not so much interested in what the maximum may be. Those are things that must be considered. They have not been considered enough in the past.

Mr. Ward Harrison (in reply): I agree with Mr. Macbeth in regard to the difficulty of ever securing a fund of entirely impartial information.

Mr. Macbeth is correct in stating that to secure the most economical service, the frequency with which lamps are cleaned should be made to depend to some extent upon the hours of burning and that the cost of such cleaning should therefore be considered as a variable maintenance expense rather than a fixed charge. On the other hand, the cost of cleaning usually forms but a very small proportion of the total cost of operating a lighting installation, and in the majority of cases it would be found more practicable to have fixed intervals for cleaning, as once in two weeks or once a month, than to attempt to determine exactly the most economical period. For this reason we have considered cleaning as a fixed, rather than as a variable charge. After the lamp user has been educated to see the necessity of cleaning

long-burning lamps at frequent intervals it may then be feasible in the case of some large consumers to take up the question of the most economical period.

I wish to commend suggestion of a previous speaker that questions of average candle-power, efficiency and operating cost be separated from those relating to color, adaptability to artistic treatment, etc. Frequently these latter considerations must be classed as talking points upon which no definite decision can be reached, and if such subjects were taken up in the papers outlined above they might easily lead to long and profitless discussion.

Mr. Pierce's attitude that the Illuminating Engineering Society is an engineering body and that the engineer is a man who can do with one dollar what any fool can do with two, has not always been in evidence in the society. Other engineering societies devote a large proportion of their time to the consideration of questions of cost and economy.

The point which Mr. Cravath raises in regard to the proper candle-power rating for fluctuating light sources is one upon which we are surely in need of more information. If a question of this character were made the subject of a paper before this society it would no doubt be possible to arrive at a method of rating which would meet with general approval.

ILLUMINATION OR EQUIPMENT?[1]

BY FRANK B. RAE, JR.

There is this peculiarity about the lighting business: we sell gas, electricity or lighting equipment; whereas the customer buys, or thinks he buys, illumination. Between the buyer and seller, then, there is a gap, and it is my understanding that the Illuminating Engineering Society's purpose is to bridge this gap.

Now, into any problem of bridge-building enter many considerations. In the first place, the bridge must be erected where the density of traffic will repay in largest measure the cost of the structure. Then it must be of such strength and size, either large or small, as will most economically accommodate this traffic. These are plain and practical considerations which interest the sordid and the ignorant. The higher problems of engineering involved are, on the other hand, technical considerations which interest, chiefly, only a few men of special training.

To apply the simile to the lighting industry, we find it necessary to bridge the chasm between the man who sells gas, electricity and equipment and the man who buys illumination. The technical problems involved are of interest only to engineers, but there are plain and practical questions which interest the least ethical salesmen, the most sodden proletarian: Where are these bridges to be built?—How large or small are they to be?

To answer these questions, the engineers must, voluntarily or perforce, look at the problems first from the public's standpoint, which is something that has not been done heretofore with any consistency. You, as engineers, must realize that you are public servants like the driver of a taxicab or a subway guard; that is is to say, a perhaps unwilling servant but in livery nevertheless. The public does not know or care about your technical problems or difficulties, and does not propose that those difficulties shall be considered above the main point—which is to erect where most needed the bridges that will accommodate the necessary traffic.

Let us analyze for a moment the work of the man who to-day is selling equipment or energy but who should be selling illumina-

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

tion. At the present time there is a simple formula for determining the amount of current required for lighting to a given intensity a room of given dimensions. This formula divides wall and ceiling tones into three classes; light, medium and dark, but it fails to define the meaning of the words "light, medium and dark" and takes no account of color. This lack of definiteness makes the formula a mere "rule of thumb" (which rule, you may remember, defines the distance from the first joint to the tip of the thumb—any thumb—as one inch).

Here then is a point where the engineers should throw a bridge over the chasm of our ignorance. We require a color chart with proper constants for determining exactly the value of wall tints.

Then, this situation is frequent. A man desiring to illuminate his premises is bombarded by the conflicting claims of many equipment manufacturers. The customer does not care at all what equipment he installs; his desire is simply to secure the best practical illumination. Yet there is no means whereby he can determine the exact facts regarding illuminants, for no data is available which either applies to normal working conditions or which bears the stamp of absolute independence.

So there is another bridge to be built.

Finally, the engineers can perform the greatest service of all by supplying, in usable form, data which may serve as the basis of popular education on illumination. In the industrial field, especially, we should know such things as the ratio in speed and spoilage between a workman operating under proper illumination and one combating the glare effect of a bare lamp hung directly in line of vision.

In this connection, let us examine briefly certain work that was done to promote industrial lighting.

Several years ago when the Holophane Company acquired the D'Olier steel reflectors it directed the writer to inaugurate a campaign of education in industrial lighting. Editors were interviewed; photographs were secured and articles prepared. Since the product exploited could be used only in conjunction with incandescent lamps, the work was frankly partisan to that illuminant. No excuse is offered for this other than the obvious commercial necessity of the case. Before the campaign was fairly launched, the Buckeye Electric Company, with whom

I am also associated, joined forces in this work. Our purpose was to show the need for better industrial lighting conditions; to show the cost, in human eyesight, in waste time and in spoilage, of goods in process of manufacture, of inadequate lighting methods; and finally to explain, so far as practicable, the way to go about improving conditions by the use of incandescent lamps.

I am no engineer, but, gentlemen, three-quarters of the the facts and figures which were cited in these educational articles which appeared in the textile, steel, shoe and similar trade papers, were the deductions of my crude and unscientific observation. The comparatively few "scientific" facts available were so generally at variance with the obvious truth, that practically all such data had to be corrected by a "common sense constant" to make it pass muster.

Now, here is the nub of this recital. There is to-day very little more practical, usable data of actual scientific value on this subject than there was three years ago. Certain engineers have deplored the exaggeration, the inaccuracies, the generalities of the articles we have published, but they have not supplied the cold, hard, inconvertible facts to supersede the only basis upon which we were compelled unwillingly to work.

The unregenerate ad-man, the boastful and seemingly unscrupulous salesman, have been compelled to erect flimsy and temporary bridges across this chasm which separates the manufacturer from his customer. They have done so, not out of choice, but from necessity; they are subjects, not for blame, but for succor.

It is hoped that these suggestions make clear the need for increased activity upon the part of this society along lines of practical development of the field.

Such activity will be appreciated—is appreciated to-day. The successful salesman of gas, electricity or equipment knows that he must base his sales arguments upon results rather than means. Comparatively few lighting installations are sold to-day except from an "engineering" basis. The members of this society may shudder at the blasphemous use here made of the word "engineering," but however mistakenly applied, the intent of the modern salesman of energy and equipment is to work along scientific

lines and to employ such engineering data and principles as he can grasp. He may pervert these data to selfish ends, but if the data is fundamental and practical it will stand upon its merits. No one can take liberties with absolute truths—and few commercial men are so foolish as to try.

The difficulty, as it appears to me is that the true engineers are overly interested in engineering for its own sake rather than for the sake of the public. Realizing their superiority (in this single subject) their effort is to rise further from the mass of humanity rather than to assist humanity to reach their level. This mental attitude is not peculiar to illuminating engineers; it obtains among other professions also. The highly trained musician despises those simple melodies which you and I appreciate and love. The experienced painter is so engrossed in brush-strokes and technique that the masterly rendering of an ugly subject to him excels in interest the simple translation of beauty in form and color.

Yet the great men in all professions and in all ages have been those who have simplified the involved and clarified the obscure. That, gentlemen, is your duty if we are all to sell illumination instead of equipment.

DISCUSSION.

Mr. E. C. Crittenden:—Without taking much time, I want to give one instance as an illustration of the point of view of the salesman who perfers to trust his "common sense" rather than to put a little study on the fundamentals of illuminating engineering, a point of view which I feel Mr. Rae takes when he states that "the comparatively few 'scientific' facts available were so generally at variance with the obvious truth, that practically all such data had to be corrected by a 'common sense constant' to make it pass muster." Not long ago a gentleman, whose card read "Illuminating Engineer" for a rather large company which deals in lighting fixtures, came to us to urge the use of some of their reflectors. One of his chief arguments was that a 100-watt lamp with reflector gave 85 c-p. downward as shown by test curves. This statement apparently did not make the impression he expected, and after a time he inquired confidentially about the reliability of the laboratory which had made the curves. It

was a laboratory in New York, which you all know, and I expressed my opinion of their work. The gentlemen replied that he had always heard that it was reliable, but since they had made that curve he had felt more or less doubtful, because he couldn't see how a lamp which gave only 80 c-p. without a reflector could give 85 with it.

Mr. E. L. Elliott:—In regard to scientific information and advertising which is about the gist of Mr. Rae's paper, he apparently deplores the lack of it for advertising purposes. Well, now, suppose that the scientific information is against you? Suppose you can't use it to advertise that particular thing, then what? Why then you have got to introduce hot air (I know this because I write advertisements) and just where and how to use science in advertising is quite an art. My own opinion is that better not intermix them too much. The public will get onto it. If you have scientific facts that will further your proposition, let them stand as scientific facts, then make your claims. Let them further your proposition.

As to the "common sense coefficient" or factor, or whatever the expression is, and the inference that the highly trained engineer is not competent to give a popular expression of a thing, there I take direct issue with the author. In my career I was a teacher, and I had the selection of text books to a greater or less extent for elementary work, and I invariably found that the clear concise understandable elementary text book was never written by a novice; it was always written by a master in the art. Take chemistry, for instance, Prof. Remsen, in my judgment, wrote the best elementary chemistry ever put out, a primer of chemistry, you might say; the same way with geology and the same way all along the line. The writers that can make scientific facts clear are not the men who take a lot of facts three fourths of which they can't understand and try to predigest them and feed them to the public.

Mr. A. J. Marshall:—I very much disagree with the ideas expressed in Mr. Rae's paper. Mr. Rae is not present at today's session. I am quite sure that if Mr. Rae had followed the proceedings of the convention, as one who is interested in illumination naturally would do, and had been a cooperator with the

society, generally, he not only would have gleaned much of the data that he makes a plea for, but likewise would have benefited the society through his suggestions. While the Illuminating Engineering Society has not given as much concrete data as we would have liked, yet no one can deny the fact that it has been the Illuminating Engineering Society, and those associated with it, that have created the general interest in the lighting world, and the field in which Mr. Rae is interested. It is also reasonable to suppose that some of the findings of the members of the Illuminating Engineering Society have acted as a sort of inspiration for Mr. Rae's admirable publicity work.

He speaks of the engineer assuming a lofty attitude—pulling away from the masses rather than attempting to work with the masses. My experience with engineers, as well as members of other professions, does not bear out such a statement. While it is true that he who succeeds in advancing his understanding is naturally desirous of elevating himself to higher planes, yet it is equally true that such advanced workers are ever striving to assist in raising mankind to higher levels. Naturally, those people who have been able to advance their thought are not going to recede because any small class of individuals are either too lazy or ignorant to follow. It should be remembered that the most advanced thinkers and workers of any time have been those persons who have been "one of the people," and the Illuminating Engineering Society, fortunately, numbers among its members many men of this type. As near as I have been able to ascertain, the members of the Illuminating Engineering Society have evolved very much more desirable data relative to the use of light than the class of salesmen which Mr. Rae refers to have been able to assimilate, and such lack of assimilation is not to be charged to the creators, but to the men who have not taken the trouble to master it, even though much of this data is available in quite simple form.

I here refer to the rather odd view set forth in the second paragraph of the fourth page of the paper, where Mr. Rae states that "The highly trained musician despises those simple melodies which you and I appreciate and love. The experienced painter is so engrossed in brush strokes and technique that the masterly

rendering of an ugly subject to him excels in interest the simple translation of beauty in form and color." I don't know what Mr. Rae's relations or acquaintance with art are: certainly no impartial, intelligent investigation would substantiate his view as just set forth. It is commonly agreed that the higher a man advances in his particular profession, a musician or painter or what not, the more thoroughly he appreciates simplicity—and simplicity is art. If Mr. Rae refers to some wild-eyed, long-haired individuals who do the things that Mr. Rae speaks of as a fad, in order that they may cater to people of lowly taste, which will mean revenue, all well and good, but such type is not representative.

No better example need be offered as to the desire of the members of the Illuminating Engineering Society, to simplify understanding of the work, than the most excellent paper given by Dr. McAllister this morning, where he reduced to simplest terms methods of calculation. This is but indicative of what the society is generally accomplishing.

My suggestion to Mr. Rae, and those for whom he may speak, is that he become a worker in the society, learn by observation and association, and in turn assist the society by his presence and constructive criticism.

Mr. Norman Macbeth:—Mr. Marshall has very completely covered a number of points to which I might have referred. I am inclined to resent Mr. Rae's indictment of the work of this society as shown by its TRANSACTIONS, and I doubt whether Mr. Rae would question my conclusion that there are few advertising men who have benefited to as great an extent through the work of this society. It is my impression that he had to a greater extent centralized the talking points about "scientific illumination and scientific fixtures" more than anyone; although he now admits here that the "few scientific facts available were so generally at variance with the obvious truth that practically all subject data had to be corrected by a commonsense factor to make it pass muster. The "three-quarters of the facts and figures which were cited in these educational articles" forming the flimsy and temporary bridges erected by the ad-man, and the "seemingly unscrupulous salesmen" to permit the manufacturer

to reach his customer have evidently sapped Mr. Rae's imagination and it is desirable, at least from the manufacturer's standpoint, that Mr. Rae have more stable bridge material furnished. Won't this society please supply "the cold, hard, inconvertible facts to supersede" the filmsy temporary structures above referred to?

We are told that "the customer does not care at all what equipment he installs." Surely advantage was not taken of that situation which later has proven embarrassing; otherwise, this campaign, if at all successful, must have opened the doors of many industrial establishments to new equipment and better conditions of artificial illumination. These doors should still be open to the engineers of the companies mentioned for a complete analysis of the results of the new installations which were placed through the strenuous efforts of the strong combination of ad-man and salesman who, as before mentioned, reached the customer over the bridge of imagination. Surely valuable information could be secured in this manner which would not only bolster up the ad-man's imagination, put new timbers into the bridges, but would result in a compilation of facts and figures which would in the end constitute subject matter, which we can thoroughly agree with Mr. Rae would be exceedingly valuable in our TRANSACTIONS.

This plea reminds me of one made a year or two ago at a section meeting, by a central station man, who appreciated the value to his sales department of a complete compilation of load and diversity factors, and kindred information on the use of central station energy in the various classes of commercial and office building installations, at different periods and throughout the year. The first move by the society to secure this information, through a committee of one or more, would have been to arrange with this representative central station for access to its books, from which practically all of the information desired could have been compiled.

I believe that members of this society would take very little exception to an exchange of useful data, but would quickly resent an exhibition of the spirit which has been vulgarly covered by the phrase "Let George do it."

THE MANUFACTURE OF GLASS FOR ILLUMINATING PURPOSES.[1]

BY E. H. BOSTOCK.

That the author should be asked to prepare a paper on the manufacture of glass for illuminating purposes is an indication of the keen interest of the illuminating engineer in all that pertains to his business. For a long time the engineer has been ever willing to admit that there is something mysterious about glass-making. He has been greatly surprised when told that common sand is the main component of glass; and when acquainted with the innumerable crystal and colored glasses that are made from such a common thing as sand his surprise has approximated bewilderment. And it is not so long since that purchasers, both large and small, of glassware accepted the products offered by glass-makers without asking any questions about them. The distance between the manufacturer and the user of glassware has, however, almost vanished—thanks to the attitude of the manufacturer, and the illuminating engineer. Now the illuminating engineer who has a problem in glass that bothers him takes it to the glassmaker who understands and is able to fulfil the requirements.

To afford a clear understanding of the subject in hand, it may be well at this point to state broadly what is meant by glass. Most of the usual descriptions of glass are misleading. Usually transparency is the property of glass first thought of; yet there are a goodly number of glasses which are not transparent, and others which are opaque. Hardness and brittleness are also characteristics of glass but not more so than of other bodies. Perhaps the only universal property of glasses is that of being amorphous in structure. So that, as a whole, glasses may be regarded as structureless solids.

Glasses, too, are characterized by the entire absence of any

[1] A paper read at the fifth annual convention of tne Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

signs of structure, and their mechanical, optical, and chemical behavior is consistent with that found in liquids. In passing from the molten liquid to the solid condition, the change in glass is gradual and perfectly continuous. No evolution of heat or retardation of cooling is found at any point. But the best conception of what glass is, and the one that will facilitate an understanding of what can be done with it, is to consider glass a molten solution of a number of chemical substances usually silicates of soda, lime, lead, and other kindred substances, cooled until their viscosity becomes so great that the body behaves as a solid.

Theoretically, one should be able to treat glass, given sufficient heat, as a liquid, to mix it to any color or to any specific gravity; to impregnate it to saturation with any desirable ingredient, to add materials to emphasize its di-electric properties, its heat conductivity, its coefficient of expansion, or any other property; and then cool it to such a state of plasticity that it may be worked to the desired shape or utensil. Practically, most of these things are done to some extent; and with such a plastic material, much more will be done in the future.

The ordinary glasses of commerce are usually silicates of soda, lime, lead, and potash, varying according to the use to which the article is to be put, and the way it is to be worked. An intimate mixture of the sand, carbonate of soda, carbonate of calcium, red oxide of lead, in varying proportions, is put into a fire-clay pot. Several of these pots are grouped in a furnace capable of raising a temperature sufficiently high to melt the required materials. This temperature is maintained until the glass has melted out clear and all the superfluous gases and impurities have been driven out of the mass. The furnace is then cooled down till the glass is cool enough to work. Incidentally, the usefulness of glass is again apparent when one realizes that at different stages of its cooling, it may be blown, cast, pressed, rolled, drawn, cut, drilled, ground, and shaped in numberless ways.

Having in mind the process of working by which the glass is to be shaped, and if other work is to be done upon it, how it is to be treated when cold, the glassmaker must vary the constituents to suit the need. The number of chemicals that may be used in producing crystal glass for various purposes are many,

being practically every salt that will enter into chemical union with silica which is always the base. For instance, about the cheapest form possible to use in cheap pressed or common blown goods would be a mixture of sand of at least 98 per cent. silica, sulphate of soda, crushed limestone and a small quantity of ground carbon. But while it would be possible to work this cheap glass, it would be so harsh and hard in nature that the loss in working and cooling would be large and it would be hard to etch and cut. To make a soft working glass carbonate of soda is used in place of the sulphate, and soft lime in place of the limestone. This makes an ideal glass to work either hot or cold and is the usual glass for ordinary lighting ware.

Lime-soda glasses, however, are not of the most brilliant texture. To produce "brilliant" glass, red oxide of lead is added to the mixture, the resulting glass being soft and having a tendency to be a little more homogeneous than other glasses. Lead glass is very easily worked when cold, and for cutting, drilling and similar working it is preferred. The addition of barium increases the above mentioned properties of lead glasses. Potash is also used in quantity in producing at less cost crystal glass with properties resembling the lead glass.

The one point in which great care must be exercised is in the final cooling process which must be of a slow annealing nature; for if the outer surface of any glass be cooled more rapidly than the interior, then internal stresses will be created which will need only a slight chance to crack the article in numberless ways. Exceedingly thin glass is the only form of glass exempt from this action.

Modern illuminating glassware may be said to have begun with the making of the lamp chimney of the Argand type. A description of the development of the manufacture of this device with its numerous modern forms will serve well to fully illustrate one largely used method of working glass for the market. The usual lamp chimney is of a kind of glass known in the factory as "off-hand" ware. This term indicates goods made by the glass blower solely by the aid of the blow pipe, with no guide in its forming other than the judgment of the eye and the hand. The blow

pipe used for small ware is usually about one inch in diameter and about fifty inches long, with one end bunted up to form a nose. This nose the gatherer, as the workman is called, first heats to the temperature at which his experience tells him the glass he is to work will best stick to it—molten glass will not stick to cold iron. He then places the pipe nose within the orifice provided, lays it upon the surface of the molten glass and turning it, causes a certain amount of the glass to adhere to the pipe. It may be that he will secure enough to fashion the desired article. If not, after the glass has cooled sufficiently, he will "gather" again upon the cooled glass until the pipe collects sufficient glass for the purpose. He will then blow down the pipe, distending the glass to a bubble which he will proceed to fashion in a variety of dexterous ways, swinging it if it needs lengthening, holding up if too hot; rolling it upon a flat surface if it needs rounding off; if it is to be flared, by chilling in certain parts and heating others; and, otherwise performing wonderful and magical sleight of hand work until he forms the chimney or other article into the needed shape. The shapes that can be made by the blower in this way are infinite in number.

A very large number of gas globes are made by the "off hand" process, and finished at the edges and holder by the blower with small hand gages. The distinct advantage of goods blown "off hand" is the fire polish finish of the surface. In many cases a glass with a surface of this kind is highly desirable, frequently absolutely necessary. It has also a great disadvantage; no matter how true the eye of the workman may be, off-hand ware will differ more or less in size and shape. To overcome this difficulty, as well as to some extent lower the cost on this class of ware, the "paste mold" process is resorted to.

In the latter process, after the blower has gathered the necessary glass and formed "a bubble," all sides of which he has kept about even in thickness, he places the bubble between the halves of a mold of the necessary shape. This mold he closes, and proceeds to inflate the enclosed glass until it fills the mold, ceaslessly turning it at the same time so that the glass will take as little imprint as possible from the mold. Between the periods of using the mold is immersed in water, so that the paste is

kept damp, and when the heat of the glass falling upon it causes steam to be formed; the steam acts as a cushion to prevent the glass rubbing hard upon the mold surface. By this process, a surface not very inferior to fire-polished is formed. But it is obvious that with the necessity of turning the ware in the mold, no article with sharp angles can be made. This is one of the drawbacks of the paste mold process. Furthermore, the article must continue to revolve as long as it is in the mold, because the end cannot be removed by the "blow over" method. The article must be closed and therefore the end must be cut off and finished when cold.

All blown ware is made by blowing the glass into a two piece mold with the shape and pattern cut in intaglio. In this process when the glass distends fully to fill the mold, the workman moves his pipe a short distance from the mouth of the mold, and blows till the unconfined glass becomes very thin and finally bursts, leaving the article the true shape of the mold and with any design the mold had upon it. Later the article is finished at the edges and placed in an annealing lehr to cool. Almost any shape can be given to the article in the mold; and the marks left upon the glass by the joint of the mold are hardly noticeable.

Most of the lighting glassware used is produced by one of the three blown methods just described. There are, however, two other processes by which minor quantities are made. The first one of these is the press method in which the article is pressed into the shape of any given mold or die by a descending plunger. This process dulls the surface considerably and is not used extensively, except for special basins where cut steel dies are employed for high relief designs; or in the forming of ware afterwards to be acid or dull finished. The second method consists of simply placing a sheet of glass upon a shaped template, and subjecting it to heat, either by means of blow pipe or kiln, until it assumes the shape of the template. This method is used for making bent lights for large work from sheets of window plate, and opalescent glass and has undoubtedly been brought out by the recent vogue for bent glass shades in opalescent glass. As it is possible to bend plate glass and fully preserve the beauty of its surface, this method is taking its place in recognized use in the

making of large fixture glass, ceiling dishes, etc. Given the time, there is hardly a shape or size that cannot be bent for these purposes. Recently many curved bends of peculiar beauty of curve have been bent from polished plate glass.

For that matter almost any sheet or plate glass may be bent if care is taken to heat and cool it slowly. Rough glasses such as antique, marine antiques, Venetian and rough plate are being bent for use with large lanterns and outside wall brackets in antique iron and bronze. By very carefully heating these glasses it is also possible to bend prism sheet glass for large work, if desired, without any disturbance of the angles. To match the large light opal globes used often in bronze torchéres and standards it is now possible to procure the same glass in sheet form and bend it; and in fact to procure and bend any sheet glass that the decorative scheme may seem to call for.

Enough has been said, without going into manufacturing details, to show that almost any shaped article can be made for lighting purposes. In passing, however, it should be remembered that the most brilliant surface is on off-hand ware; the paste mold next, then in order mold and pressed ware. Since the advent of sheet glass, there is probably no limit as to size which may be set for chandeliers or fixtures that cannot be met.

If one has kept in mind the definition urged previously in this paper, it might be stated here that molten glass can be made any color; this is almost literally true. All colors are gotten by the addition of metallic oxides to the mass, and very great difficulties are sometimes encountered in their action at high temperature; but in the end, these are overcome and the expert glassmaker will furnish any desired tint of color.

The question of color so far has interested the engineer, only in so far as he has desired to procure as nearly as possible a certain color. For instance if he desired a ruby glass it mattered not if the color were gotten with gold chloride or flaked copper, which produces rubies almost exactly similar in tone; and yet there will be differences in absorption that must be studied.

Colored glasses may be divided into two groups. One, probably the largest, includes glasses in which the coloring matter is held in true solution; that is, it is present as a silicate or other compound salt which is soluble in the glass. The second group

contains those in which the coloring salt is probably held in mechanical suspension in a finely divisible form, approximating a "colloidal solution." This suspension of the particles of coloring matter has been proved by the researches of Siedentopf and Szigmondi in ultramicroscopical work. In ruby glass, whether of gold or cuprous oxide, these particles have been made optically evident.

In glasses of the latter group the color may be altered by processes which involve heating and cooling at different rates. A rapid rate of cooling produces a different grouping of the minute particles and alters their size or shape, or even causes them to go into and remain in solution in the glass. Many manufacturers have dearly bought the experience that the dropping of furnace temperature may cause the production of a very different tint or even distinct color from that which he thought he had.

A large number of colored glasses may be produced by two entirely different substances; but each of these glasses will have different optical and absorptive qualities making one sometimes preferable to another. Copper in a cuprous form produces a great variety of rubies, as also do gold and selenium, while copper reduced to the cupric form gives intense greens. Silver gives beautiful ivory tints sometimes approaching ruby. Sulphur, as the sulphide of cadmium, and the sulphur compounds of barium produce deep greens and yellows. Carbon enters frequently into glass as a reducing agent in producing other colors. It may be added in almost any of its numerous forms as their peculiarities serve. Ground coke, charcoal or coal are used most frequently. Sawdust, straw, and often, strange as it may seem, potatoes are used for certain ends. Carbon in its finely divisible form produces amber glass, for which it is very useful. The nature of the fixed carbon causes the tint to persist despite any rapid cooling or other practises in which less stable colors will not serve. Tin oxide is used to produce opal glass as are cryolite, fluorspar, feldspar, fluoride of aluminum, calcium phosphate, etc. Chromium salts are used for various greens as are manganese for the colors from pinkish to purple and nickel for greenish browns. Cobalt is very largely used in producing blues. Every glassmaker has his own particular ways of mixing to produce desired colors and tints.

A large number of glasses, however, are too strong in color for use in blowing, lighting glassware, and resort is had to the flashing process of placing a very thin layer of the color upon the inside of an article of crystal glass. This is done by having the workman first gather a small quantity of the colored glass upon his pipe and afterwards the needed quantity of crystal. When the article is blown it has on the inside a flash or film of the color very evenly applied. This process also admits of pattern work being done upon the article by the cutting or etching away of the flash in definite patterns.

Before the coming of the illuminating engineer, the making and using of color was in the hands of the manufacturer, who often produced a color that fulfilled his idea of a new and striking glass and proceeded to market it, hoping it would be a "good seller." Now if the color happened to be a striking one, it sometimes originated a "craze" that carried it into many places where it did not belong and produced great discord in many color schemes and in architecture. To-day most of the glassmakers' products are made for definite purposes, and according to more scientific plans.

When employing color in glass, the light source must be taken into account, if the desired results are to be considered. For instance, the yellow light of a gas flame or of some flaming arc lamps changes considerably the value of any green in glass. This is true more or less in all cases; but it may be avoided by the use of glass of sufficient complementary color power. Then, too, it should be noted that the cheaper grades of clear glass are not crystal. A globe or shade may be blown from cheap greenish glass. This kind of glass will, of course, affect the value of the light.

The problem of coloring glass is now receiving more attention than at any time in the past. Engineers are striving to get the near-daylight effect with some of the new lights. The colorimeter has shown about what is needed. Glasses have been devised to screen out the ultra-spectrum rays of light from different illuminants. Schotté, for instance, has succeeded in screening out of the ultra-violet rays.

Prolonged exposure to light also has the power to change the color of glass; strong sunlight, exposure to ultra-violet rays,

and the emanations from high powered incandescent gas mantles all have a tendency to tinge crystal glass purple, if the glass contains any manganese. Numerous instances of the latter phenomena have come to the authors attention. The change of course is only slight and usually occurs in street lighting where incandescent gas is frequently used in high powered group lamps. Still the engineer must note this in cases of interior installations where color may count. In the production of the cheaper grades of crystal lighting ware manganese is often employed to correct the green color caused by the use of inferior sand.

Frequently, an illuminating engineer will find cases where it is necessary to reduce the intrinsic brilliancy of electric incandescent lamps. To do this two methods are available: the bulbs may be coated lightly with paint, or frosted. The latter process is susceptible to great variations, depending principally upon the strength of the etching acid used. It remains, therefore, for the engineer to specify the grade of etching desired. As for painting the bulbs, this is always a mere makeshift, because a painted bulb can never attain the beauty of the soft colored globe. Besides the coloring of the lamp bulb always has a more or less deleterious action on the life of the lamp due to the increased temperatures. Where the color must be changed, an enclosing globe of the desired tint should be used whenever possible. This globe should, of course, be of such size as to permit the heat generated by the lamp, and by the absorption effect of the globe and coloring matter itself, to radiate freely. In general the deeper the tint used and the farther the tint departs from the red-yellow end of the spectrum, the greater will be the amount of light transformed into heat.[1]

As a matter of interest it should also be noted that acid etching brings out the body color of glass. Some beautiful tints may be obtained by aciding colored globes.

In connection with color, the glassmaker recognizes a condition that he calls "texture," meaning a softness of tone which causes one glass to be preferable to another, although they may be of apparently the same color. The general understanding

[1] P. F. Bauder, *Trans. I. E. S.*, Feb., 1911.

is that the glass of highest specific gravity and density is usually the "softest" to the eye.

In the use of the sand-blasted finish on glassware, the dirt problem is introduced. Rough finished glass globes will gather dust and dirt and cause a loss of light flux. Besides a rough etched globe or reflector is seldom required to conceal a light source. When the loss from absorption and dirt is considered there is an apparent reason why the illuminating engineer should specify a softer finish than "sand-blasted." A white acid finish can be made in any intensity from that known as "satin" down to the more heavily etched finishes. Usually a manufacturer of glass has available a number of samples from which the engineer may select the finish best suited to his requirements.

The author cannot leave the question of color without beseeching illuminating engineers to study their color problems more carefully. So many beautiful decorative schemes have been spoiled by light of the wrong value, or the desirable daylight effect ruined by globes whose surface color was at variance with the decorations and trim of the room. Let the engineer study the problem carefully, and if the glass color he needs is not found at once he should keep on looking and asking until he gets it.

REFLECTING GLASSWARE.

Reflection for concealed cove and molding lighting is apparently solved by the use of the ordinary silvered fluted glass of commerce. For such purposes it gives the greatest known efficiency under the conditions but the avoidance of the glare by those who must necessarily face it in footlight, proscenium and chancel arch lighting, is more difficult; though the adoption of the gold backed reflector as now used to take the glare out of electric headlight reflectors will undoubtedly help when used for this purpose.

The manufacture of diffusing and reflecting illuminating glassware, has been taken up very thoroughly by one company whose data and photometric readings are in the hands of most lighting engineers. This same data is very full. Knowing the angle of deflection, it is only a question of mathematics to say at what angles the prisms of glass shall be arranged to catch and project light from any given light source in any di-

rection, and by arranging the prisms to the strength of light flux to make almost a perfect distribution. The use of such ware is growing; and with it of course some abuses are creeping in. Imitation ware of incorrectly calculated and arranged angles and inferior glass produce a variety of poor and undesirable results. Such ware must be used with discretion.

For ceiling reflection, where the ceiling may be a dark and absorbent color, the use of glass reflectors is advised. The highest efficiency of course is obtained with silvered fluted glass. Dense white opal glass is also effective. Both these glasses may be gotten in any shape. The fluted reflectors may be obtained by bending the sheet glass, as may be the opal glass, if the proper shaped reflector is not made in blown goods.

The question of diffusion has been studied a little further in the matter of concealed dome lighting where high powered lamps are used above a decorative glass dome. It is evident that brilliant spots and dense shadows would entirely spoil the effect aimed at in the glass work, and also detract from the beauty of the room. So diffusive sheet glasses have been devised and are now made that break up the light and leave the domed ceiling apparently one even glow of light, and with an exceedingly small absorption of light flux. For diffusive lighting the newest and the best development is that of the already well known phosphate glasses. The phosphate glass is the only glass which is not a clear colored solution; for it holds in a state of suspension innumerable particles of an opaque white color. Each one of the particles catches and breaks up the light causing its diffusion over a wide area. By the use of phosphate glass a light source may be concealed so as to emit a soft and restful light. Moreover, this glass enables diffusive illumination to be obtained without the use of either sand-blasted or prismatic globes, thereby avoiding the collection of dirt which reduces the light flux. It can also be worked into any shape by blowing and pressing. The author believes, too, that no difficulties would be encountered in coloring it, although he has never seen it done. The inherent qualities of this glass will probably introduce a lot of imitations. The ordinary opal glasses of commerce are finished to resemble the phosphate glass, but they are lacking in several respects. principally in the element of diffus-

ion. A close examination by a sharp eye will disclose the suspended particles in the real glass.

Undoubtedly there will be a big demand for this glass, particularly in large public building fixtures where it will be needed in large sizes. At present it is being marketed in sheet form from which any shape and size may be bent.

At this time also a number of alabaster glasses are being designed to give the exact effect of the true carved alabaster and they succeed very well in doing this. The engineer may have bowls pressed in some of the old hand carved designs, and have them finished into very beautiful fixtures, having none of the discolorations which often appear on true alabaster.

Opalescent glass, while it has been used in recent years is not of much interest to the engineer. It must be considered as a decorative glass; for as used, it is too absorbent, and its colors are too wild and variant to be of much practical use decoratively. For portable and dining room shades, etc., though, it will probably remain in vogue for some time.

There is one grade of this glass known as Eutruscan opal coming in several densities with a "granite" surface treatment which has a reasonably low absorption coefficient and produces very beautiful effects. Other forms of opal glass with depolished and otherwise treated surfaces are used for several makes of reflectors, where the reflection is largely diffuse surface reflection and there is little or no loss due to the light having to pass through the glass body as in prismatic and mirrored reflectors. The appearance of this glassware is very fine. The glass is made in several densities, the lighter densities sacrificing efficiency for flame and other translucent effects.

No word has been said about the incandescent bulb itself; and there is little to be said. Only a few variations from the ordinary shape have been tried; but there can be no useful purpose served except to fit certain size openings, or afford a prismatic surface and thus diffuse the light. Of course, it is possible to produce any color of bulb which might be called for, if sufficient quantities to make it commercially possible are demanded.

In daylight problems, the engineer's chief concern will be to redirect the daylight in as much as may be possible to the points

of an interior where it is needed. It may be taken for granted that the architect will attend to the size of windows, skylights, domes, etc., although the engineer has often been called in when these have proved inadequate. The chief help in getting the needed daylight into a building is prismatic glass of some form or angle. By prism glass, is meant any flat glazed glass with prisms so arranged upon its surface to catch the falling light and deflect it into the building. The different types are the pressed prisms, rolled prism sheets, blown, fluted and illuminal glasses. The first two are mainly used; and in the case of the latter of the two, definite data is easily available for the engineer, in which a formula is evolved from the height of surrounding buildings, and width of street, etc., to find the angle giving approximately a horizontal light flux into the building, and a whole series of different angled glasses are furnished at call to meet most of the needs that arise. The smaller pressed prisms in any angle are also available; but they necessitate many metal or wooden strips to hold them in place, thereby casting shadow, and holding dirt so that the use of the sheet prism is advised wherever possible.

One great objection to the use of prism glass has always been that its sharp drawn straight lines do not conform to any decorative scheme, and it therefore always seems misplaced. Recently, however, a wavy lined prism glass was marketed. This glass at any certain section shows a true definite angled prism, but its wavy line enables it to be used with ease in decorative schemes.

The fluted glass, which was the forerunner of prismatic lighting, is not as good in deflection on account of its shallow prisms; but its blown surface is smoother and less retardant than the other rolled glasses, and it can be used to advantage in leaded glass combinations for minor lighting requirements.

In skylight lighting where it is desirable to reach the side walls with a maximum light flux a double arrangement of prisms must be resorted to. This involves a rather intricate problem, but it can be figured out successfully.

At this point it occurs to the author that there are many points of difference between glasses, colors, shapes, etc., that have been left unsaid, and that even the main points have been mentioned

only briefly. The limits, however, of a paper of this kind are of necessity narrow. But the main point which the author has tried to emphasize is that glass is an exceedingly mobile material with which to work, and that by some known or used process or elaboration glass may be produced almost any shape, size or color for whatever needs an engineer may have in lighting problems.

DISCUSSION.

Mr. V. R. Lansingh:—On the fifth page of Mr. Bostock's paper is the statement, "This process dulls the surface considerably and is not used extensively, except for special basins," etc. He is perfectly correct in that the process dulls the finish of the glass. This method, however, is used extensively inasmuch as all prismatic reflectors are manufactured by the molding process. If one takes a reflector, or a piece of glassware, coming out from such a mold and examines it under a magnifying glass—and the glass doesn't have to be very powerful either, the ordinary little glass, fairly strong, will do—little ridges and crinkles in the surface of the glass will be found. These are due to the cooling of the glass in the mold at unequal rates, and inasmuch as we are dealing with light rays we will find that these interfere more or less with the reflection or refraction of the light, as the case may be. Now, in order to overcome this, the reflector is placed in a furnace of gas and all these little specks or striations are melted off resulting in an extremely high fire-polish which is equal to the first type of glassware mentioned here, namely, the off-hand process. So that with a finished reflector of this type as high a surface brilliancy as is known in glass making is obtained, provided it is fire polished correctly.

On the twelfth page of the paper Mr. Bostock says: "Other forms of opal glass with depolished and otherwise treated surfaces are used for several makes of reflectors, where the reflection is largely diffuse surface reflection and there is little or no loss due to the light having to pass through the glass body as in prismatic and mirrored reflectors." I would like to comment briefly on that statement. In mirrored reflectors the light—I am

speaking now of commercial reflectors—passes through the glass, is reflected from the mirrored surface of the back and then through the glass again, entailing a double loss in passing through the glass. This is also true in the case of prismatic glass where the light passes through the surface glass to the prisms, then across and back through the surface glass and out of the mouth of the reflector. In both cases there is a loss. However, inasmuch as the light passes through a medium of clear glass this loss is extremely small—in the neighborhood of a comparatively few per cent., not over, probably, ten or twelve at the maximum. Mr. Bostock seems to think that opal glass reflects largely from the surface particles of opal. I think that is entirely wrong. If that were true, one could take an extremely thin envelope of opal and it would be as good a reflector as a thick one. As a matter of fact, that isn't true. Opal glass to be at all efficient as a reflector outside of the surface reflection, which is common in all forms of polished glass, must have considerable thickness. In the case of a glass like Alba where there is colloidal suspension one finds that the reflection is comparatively small, and the absorption consequently is small. In other words, the light passes through the glass with comparatively small absorption and is not reflected inasmuch as the particles are close together. For example, the figures given in Mr. Young's paper show that of a total flux, not of the lamp but of the resulting flux, only sixty-three per cent. is below the horizontal and the balance is above, showing that the total reflected light is comparatively small. In the case of the milk opals one finds that in order to get good reflection there must be considerable density because the light penetrates into the glass and is reflected not only from the surface of it, but from the clear glass back. As a matter of fact, the outer skin of an opal reflector plays an extremely important part in the reflection. The light is reflected from the opal particles to the outer skin, and, striking as it does in many cases the less than critical angle is totally reflected back into the reflector, through the opal and out of the mouth of the reflector; and this plays an extremely important part. The matter, however, has been gone

into quite fully in the paper which I gave in the Johns Hopkins lecture course.[1]

Mr. J. R. Cravath:—There is a need, which some of us have felt, for a certain kind of glassware which apparently the manufacturers have not yet met to any extent. I would like to call attention to it here in the hope that more thought may be directed along that line. Frequently a glass perfectly smooth is required, so that it can be easily cleaned and yet have about the diffusing qualities of ground glass. Such glass is needed in the making of skylights above which it is some times necessary to place lamps with reflectors; or in the manufacture of lanterns either of wood or metal at the bottoms of which is required diffusing glass of very light absorption which will not show the lamp filaments. If there was available at any fixture manufacturer or glass house a glass in large flat plates that would have about the absorption and diffusing quality of ground glass and yet not have the roughness of ground glass, I think it would be a very desirable thing. At the present time ground glass has to be used, and you all know that it is only a short time until that gets dirty and it can never be thoroughly cleaned after it is once very dirty.

[1] Lectures on Illuminating Engineering. (Johns Hopkins Univ. Press), vol. 1, p. [illegible].

SYMPOSIUM ON ILLUMINATING GLASSWARE.[1]

INTRODUCTION.

BY BASSETT JONES, JR.

It has seemed to the committee on papers that there are several subjects which bear a very close relation to the profession of illuminating engineering which have been treated before the society in a more or less spasmodic or one sided way. It has seemed wise that an attempt should be made from time to time to gather together into one place the best thought and knowledge available in these subjects and so present what, for lack of a better term, is called a symposium on these subjects.

It was the desire of the committee to have presented at the 1911 convention of the society a series of papers dealing with reflectors in general, both glass and metal. The papers on metal reflectors were not attainable, however, as all but one of the gentlemen who were asked to contribute, like many of those who were approached by the committee on other subjects, pleaded pressure of other matters. This it should be understood is nothing unusual. Indeed it is the fate of every paper's committee to be compelled to fill gaps in a hoped for program by more or less irrelevant matter obtained either by force or suasion from other gentlemen, either not so pressed with business or who fortunately have the good of the profession close at heart. For this reason the committee has had to withdraw Mr. Marshall's interesting contribution on the metal reflectors which was included in the system he described in following symposium.

The committee believes that there is much more to be said on the subject here presented that can be encompassed under the title "reflectors," merely. And it is to be noted that each of the three gentlemen who have entered into the scheme of this symposium harp more or less forcibly on the fact that in many,

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September 25, 26, 27 and 28, 1911.

if not most cases, the science of illumination must give way to the art of the illumination. The feeling is rife among all illuminating engineers that lighting devices which give light by which to see must in themselves be pleasant to see. This is evidenced on the part of manufacturers of reflectors by the constant modifications of reflectors at first designed solely with regard to the dictates of science, toward shapes and forms in which beauty makes itself more and more apparent—often, if not always, resulting in a loss of prestige of that high priest of engineering, efficiency.

It may not be out of place to add here brief references to two other papers which with the foregoing symposium were intended to provide a complete program for one whole session of the convention—"The Manufacture of Glass for Illuminating Purposes" by Mr. E. H. Bostock, and "Requirements of Modern Reflector Design" by Mr. F. L. Godinez. Glass working as an art has had a conspicuous revival during recent years, and Mr. Bostock has written down how all sorts and kinds of wonderful and beautiful effects, which open an almost unlimited field to those concerned with lighting problems, can be obtained. Glass is one of the principal mediums with which the illuminating engineer can work, and it behooves him to acquire such a familiarity with its nature and possibilities which alone can give him the necessary facility in its use.

Mr. Godinez in his paper directs attention to some important factors which influence the manufacture and design of reflectors and glassware for present day use.

The committee has, therefore, included as part the program of papers for the 1911 convention of the society first, Mr. Bostock's paper dealing with the nature of glass and what may be done with it; second, the three papers by Messrs. McCormack, Marshall and Young giving accounts of what has been done in three different manufactories where glass is fashioned into "illuminating glassware," and lastly, Mr. Godinez's paper showing how various effects are and may be obtained with different kinds of glass treatment and illustrating how fertile a field lies open to the experimenter in this line.

PART I.

BY GEORGE H. McCORMACK.

In the manufacture of reflecting and diffusing glassware it is necessary to consider many other problems than the obtaining of distribution curves of various forms. In all sections of the country lighting companies are organizing what is termed city beautiful campaigns, and these have a most important bearing on reflector design. While many of these campaigns are confined to street lighting improvements, they ultimately result in a desire on the part of the merchant to improve his own installation. And, of course, while every one understands that in lighting installations of the better sort the fixtures and reflectors are specially designed and specified by the architect to harmonize with the historic ornament of the architectural period portrayed, there has been a fallacious opinion up to the present, that in the ordinary store or office installation any arrangement of the lighting accessories which tended to produce "uniform illumination" would meet all the requirements. On the contrary, and from both the viewpoint of the public and the lighting company, installations of that sort are most undesirable. This is because they react against the interest of the lighting company by causing the merchant to feel that he has little or no choice in the selection of his equipment, and the public influence therefrom is to discourage originality and appearance in illumination design. Then, too, a merchant does all he can to make the interior of his shop entirely different from those of his competitors', and just as unlike any other shop as possible, with the exception of his lighting system which is generally a duplicate of the sterotyped fixtures and reflectors which have become commonplace on account of inartistic appearance. How to avoid monotony in design is one of the most difficult and important problems which must be solved by the manufacturer of shades and reflectors; for he must not only allow sufficient latitude in design to conform the lines and proportion of his product to the sketches of the architect, but he must also eliminate any prominent and undesirable characteristic features which when identified

with commercial reflectors would naturally prohibit the adoption of more artistic types having the same feature.

At the present moment there is no problem of greater import to the manufacturer than this particular subject of monotony in lighting installations, and it can only be solved by carefully analyzing the trend of public sentiment, and then designing efficient units which must offer from the esthetic viewpoint a wide and pleasing choice to the consumer.

In connection with eye strain the subject of intrinsic brilliancy is another problem which demands serious consideration, but not to so great an extent when designing reflectors with a depolished inner surface giving perfect diffusion. When one considers the tremendous increase in intrinsic brilliancy of our illuminants within the last few years and realizes how the eyesight of a nation has suffered, the method of procedure of the manufacturer should be plain. Reflectors of clear glass which act by specular reflection produce a decided and objectional glare effect, and all attempts to decrease glare from such units by etching or similar means of treatment have been attended by a loss in efficiency which does not compare favorably with the results attained from opal reflectors with special depolished inner surfaces. Conservation of vision demands that the modern reflector must be of a type which can be directly scrutinized from below with perfect eye comfort; and evidently such a reflector must have an inner surface free from spots, streaks and lines of high intrinsic brilliancy.

One of the most difficult things for the manufacturer to realize is that he must refrain from unloading an unimproved product in supplying a demand which exists through public ignorance. Instead he should constantly endeavor to meet the changing conditions of progress and civilization by modifying his product, even at a less profit for the time being. Moreover, the day has come when hygiene of vision and recognition of artistic considerations must be observed.

Another fact that is often lost sight of is that differences of efficiency between any two different kinds of properly designed reflectors of the same general type are entirely insignificant. It is true that a variation in light distribution curve may be effected by changing the shape of a reflector acting by specular

reflection from a polished inner surface; but such a change is always accompanied by a glare effect, which renders the unit not only disagreeable to look upon, but also productive of additional glare from the impingence of direct, reflected rays

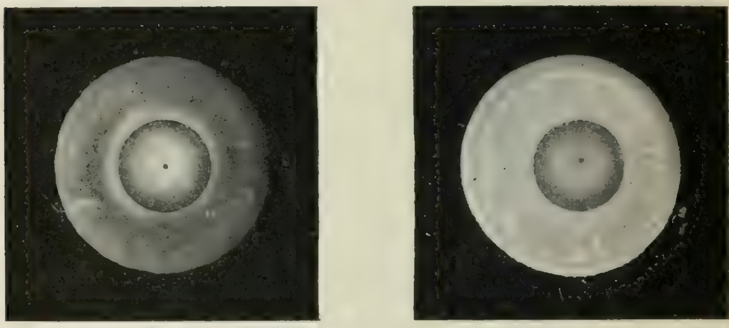

Fig. 1.—A reflector with a depolished surface (on the left) and a similar reflector with a polished surface.

of light from the polished surfaces of furniture, pictures, mirrors, a reading page, wall paper and ornaments—all of which contribute to eye strain and discomfort.

In figure 1 the two illustrations tell this story much better than words. The plate of the camera of course shows what the retina of the eye would feel. The reflector on the left is an opal re-

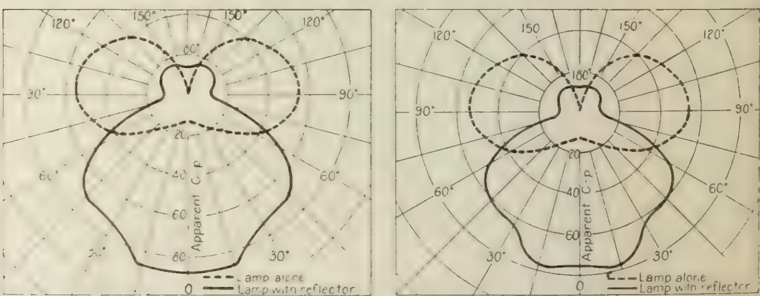

Fig. 2.—Distribution curves from the reflectors shown in fig. 1. (The depolished reflector curve is on the left.)

flector with its special depolished inner finish. The one on the right is of the same type of reflector with an untreated or polished inner surface.

Figure 2 shows the distribution curves from these reflectors,

and from which it is evident that modification without glare accompanies the distribution of the reflector with the depolished inner surface.

Figure 3 shows the distribution curves for a flat type opal reflector. The reflector on the left has a treated inner surface, but the one on the right has not. Naturally a reflector of a flat type

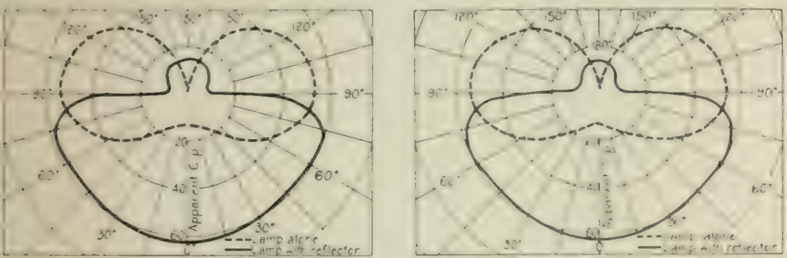

Fig. 3.—Distribution curves from a flat type opal reflector. (The curve on the left is from a depolished reflector: the one on the right from a polished reflector.)

intercepts less of the horizontal flux from the source, and consequently there is less difference in the shape of the curve than in the case of the bowl type of reflector which practically covers the illuminant. But here again one is confronted with the factor of glare, for the flat reflector offers too great an area of visible polished inner surface; while the depolished inner surface of the flat type produces no glare whatsoever.

But, as previously stated, there are other considerations of more importance than the variation of distribution of light flux from

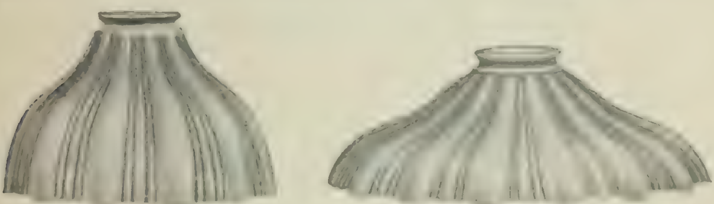

Fig. 4.—Typical opal reflectors.

reflectors of a similar type. For example, the factor of appearance, which has received but slight recognition in the past, must be considered. With reference to opal glass the transmission of light through it is accompanied by perfect diffusion from the minute particles of opal suspended within the glass, and it is this

effect which lends the sparkle, color and life characteristic of opal in reflector or enclosing bowl form. By changing the density of such glass one can also obtain the most beautiful effects by varied transmissions of light.

It is necessary in the manufacture of reflectors to provide for a useful distribution of the light flux without interfering in any way with any exterior ornamentation or variation in form which the architect might consider proper. In preparing reflectors of opal with depolished inner surfaces, care is taken to leave the outer surface so that it can be molded in conformation with any artistic treatment. Very often exterior designs can be made in the mold so that they stand out on the surface of the glass in strong relief. Then, since this gives added thickness to the glass at these points, the absorption is consequently greater and the designs offer a pleasing contrast with the mellow tone of their background. The varied appearance of such design is limited only by the artistic precept of the designer and the limitations of harmony with historic ornament. In the use of glassware with fixtures—and it is ridiculous to consider them as separate factors—the harmony of the contour of reflectors with the proportion and line of the fixture must be maintained.

It is only by constantly changing a product to meet the requirements of constantly changing conditions that a manufacturer of reflectors may hope to achieve success and feel that he has done his best to better the conditions of civilization by an observance of those ethics which to-day are being given but slight recognition in the commercial field of artificial illumination.

PART II.

BY ALBERT JACKSON MARSHALL.

The Holophane system of illumination has as its object the control of artificial light in a manner which will satisfy the physiological, psychological, esthetic and physical features involved. How this is accomplished is described in this article.

The Holophane system of illumination was the first to employ prismatic globes and reflectors having as their chief merit, the efficient control of light from various forms of artificial illuminants. In the older types of these globes, having both internal and external prisms, a low, uniform, intrinsic brilliancy, in addition to efficient distribution of light, is obtained. The globes and reflectors in this system are designed for all forms of light distributions, which is accomplished by the use of scientifically designed prisms made of glass having a high index of refraction, molded into various enveloping formations. This system, as it was then developed, was presented in a paper[1] before the Pittsburg section of the Illuminating Engineering Society, April 13, 1907. Since that time a number of changes and additions have been effected, which, together with a review of the features cited in the aforementioned paper, will be treated with in this paper, thus bringing together in one article the principles of the Holophane system of illumination as it now stands.

The Holophane system of illumination, as the name implies, is a system, not merely a few similar types of reflectors or other glass formations designed to accomplish general results; but globes and reflectors of various media, especially designed, constructed and treated to obtain definite effects, as best suited to the conditions involved. In this system, at this writing, are incorporated the following general types and features, which will be more specifically set forth later on.

[1] Van Rensselaer Lansingh, "Prismatic Globes and Reflectors," TRANS. I. E. S., vol. 2, p. 371, (June, 1907).

CLASSES.

- Class 1
  - Prismatic, semi- and totally, enclosing globes
- Class 2
  - Prismatic reflectors.
- Class 3
  - Combination of Classes 1 and 2
    - One-piece units.
    - Two-piece units.
- Class 4
  - Combination of Classes 1 and 2 with other glassware.
    - Class 1 and other glassware.
    - Class 2 and "satin finished" glassware in one and two pieces.
    - Class 2 and milk (opal) and tinted glassware in two pieces.

Class 1. Prismatic, semi- or totally-enclosing envelopes in various forms, having both internal and external prisms; these prisms both redirect and diffuse the light flux which strikes the inner surfaces of such envelopes.

Class 2. Prismatic reflectors in numerous shapes, designs and treatments, giving any desired distribution of light; most of these reflectors have vertical external prisms and clear inner surfaces.

Class 3. The combination of Classes 1 and 2.

Class 4. The combination of Classes 1 and 2 with clear, ground, acid treated milk (opal) tinted and other glasses not having as part of themselves prisms; this glass is used primarily for diffusing and artistic effects.

Aside from the principal classes just mentioned, there are a number of units made possible through a combination of these classes, which will be treated with in the body of this article.

PRINCIPLES—(CLASS 1)

Prismatic glass globes consist of a series of vertical, internal,

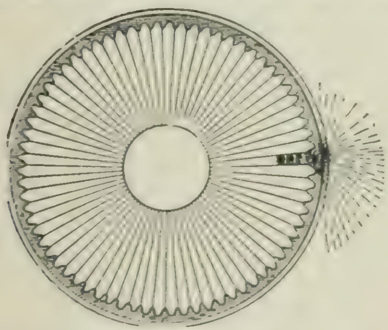

Fig. 1.—Cross section, looking at top of prismatic globe, showing internal prisms breaking up the light rays.

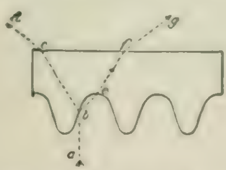

Fig. 2.—Showing enlarged view of internal prisms and how the rays of light are broken up into two or more components.

diffusing prisms, shown in figs. 1 and 2, combined with a series of external, horizontal, compound, redirecting prisms, having

both refracting and reflecting faces, as shown in figs. 3 and 4. These envelopes are based on the laws of optics, employing the principles of refraction and reflection for changing the direction of rays of light; the principle involved being associated with the oldest branches of modern physics. The application of these principles, however, to the use of artificial light is more recent. Numerous experimenters have tried to use either one or the other principle in their effort to redirect the rays of light; but it remained for Blondel and Psaroudaki to combine both principles in compound prisms, and thus lay the foundation of the modern science and art of prismatic glassware for artificial lighting. The principles in their invention were announced in the United States and the inventors were awarded the John Scott legacy medal by the Franklin Institute.

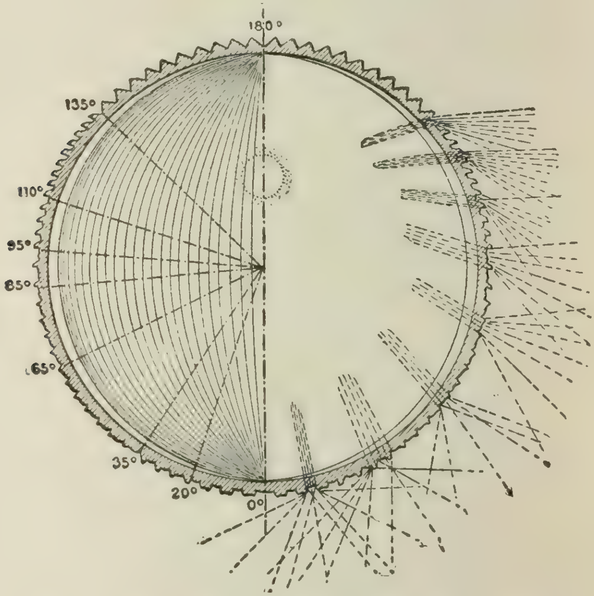

Fig. 3.—Vertical section of prismatic globe showing method of redirecting rays of light.

The function of the internal prisms is simply to break up or diffuse the light rays; the method by which this is accomplished is clearly shown in figs. 1 and 2. It will be seen, from fig. 2, which shows an enlarged section of the internal vertical prism,

that a ray of light *a* impinging at *b* will be broken up into two or more diverging rays, so that the eye, following back each ray, will no longer be able to see the light source, and that the light is diffused.

The external, horizontal prisms are in general compound, that is, they consist of both refracting and reflecting faces, as clearly shown in fig. 4. It is evident that rays of light, coming from the right direction, and impinging on the surface *c′ a′* will be simply refracted, or bent from their original course. Owing to the fact that rays of light can be bent or refracted to only a certain extent, advantage is taken of the critical angle or angle of total reflection, so that when it is desired to bend the rays of light

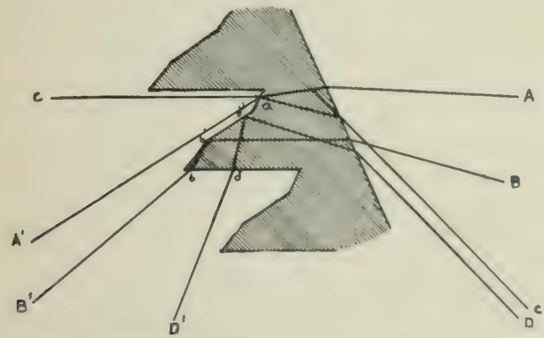

Fig. 4.—Enlarged view of external prisms showing refracting and reflecting surfaces.

more than is possible by refraction, the face of the prism is designed to reflect the ray to the lower surface of the prism, where it is again bent by refraction to the desired angle. It will thus be seen that it is possible, by correctly designing the surface of each prism, to obtain almost any desired distribution. In this connection, it should first be noticed that the prisms are in a definite position, as shown in fig. 3, and if the position of the source of light is changed from that for which the globe was designed, the light rays may no longer impinge on the surface of the prisms at the angle for which they were calculated, with the result that some of the rays may be thrown back into the globe, and thereby largely lost. For this reason, each globe is designed for a given size and shape, and different kind of source of light.

SCIENTIFIC VERSUS NON-CALCULATED PRISMATIC GLOBES.

Prismatic globes are made of pressed glass having an especially high index of refraction, which prismatic formation has been duly calculated by geometrical optics, and which insures their wonderful property of low absorption and accurate results. Prismatic globes, made of glass having different indexes of refraction, whose prismatic formations have not been carefully calculated, give results that are, in some cases, startling—the opposite to that desired.

Fig. 5 shows comparative curves of a scientifically designed

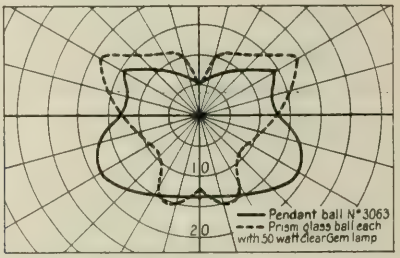

Fig. 5.—Photometric curves of scientific and non-calculated globes.

globe and a non-calculated globe. These globes are identical in shape and size. It will be noted, in the case of the non-calculated globe, that the maximum flux of light has been redirected in the upper instead of the lower hemisphere, the light being thrown where it is usually not desired. The absorption in such non-calculated globe may vary from 30 to 40 per cent., owing to the fact that the prisms may throw the light back into the globe instead of out. Perhaps the most elaborate and thorough tests on this subject were made in the Massachusetts Institute of Technology,[2] where the mean of the test on scientifically designed globes showed a loss of 12.3 per cent.; while the non-calculated prismatic globe, of same shape and size, showed a loss of 34 per cent. It will be observed, in fig. 5, that through the use of scientifically designed prisms made of glass having a high index of refraction that the maximum flux of light is redirected in useful directions below the horizontal. Such a globe as previously stated, has a comparatively low absorption.

[2] *Technology Quarterly*, March, 1902.

EFFECT OF DUST.

It should be borne in mind that the surface b' d' (fig. 4) acts by total reflection; and since a reflecting surface is generally unaffected by a substance resting on it—but not in optical contact, such as, for example, dust—the effect of such substance is far less than might be imagined. Undoubtedly, the numerous prisms tend to collect dust, but, peculiarly, the effect of dust on a scientifically designed prismatic globe is less than with an ordinary smooth surfaced globe.

In a certain test, where a scientifically designed prismatic globe was hung pendant for several months in a dusty place allowing a heavy coating of dust to accumulate on its outer surface, but with its opening covered to keep the dust from getting

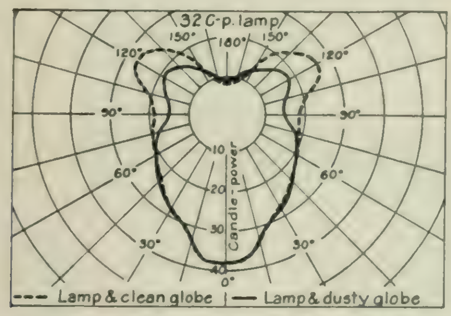

Fig. 6.—Photometric curve showing effect of dust on prismatic globes.

upon its inner surface, the loss of light due to dust was only 13 per cent., almost all of which was in the light distributed above the horizontal. The results of this test are shown graphically in the photometric curves illustrated in fig. 6, the dotted line being the curve when the globe was clean, and the full line when dusty. While it is apparent that the loss of light due to dust, in this particular test, was not great, yet it is advised that prismatic, as well as all other types of glassware used in connection with artificial illuminants, be cleaned at reasonable intervals, enabling the installation to be maintained economically.

DISTRIBUTION.

As stated before, it is possible to get practically any distribution of light desired by correctly designing the prisms. In practise it has been found that three general classes are sufficient for

most purposes. However, it should be known that each of these three classes have globes of various shapes and sizes that distribute the light in a manner which, while related to the specific class with which they are associated, gives a distribution particularly well adapted to special conditions. The three classes referred to are designated as A, B and C. Class A is designed to throw the strongest light directly downward. Class B is designed to throw the light in all directions below the horizontal. Class C is designed to re-distribute the light flux in all lateral directions below the horizontal, the maximum intensity being had at about 15 deg. to 20 deg.

HOW TO DISTINGUISH BETWEEN CLASS A, B AND C GLOBES.

In the accompanying illustrations (figs. 7-15) it will be ob-

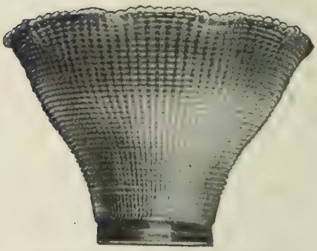

Fig. 7.—Upright Class A globe.

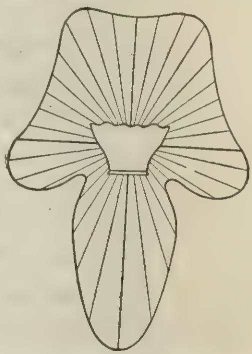

Fig. 8.—Characteristic distribution of upright Class A globe.

Fig. 9.—General distribution effect obtained with upright Class A globe.

served that the distinguishing feature of class A globes is that each prism has the same general shape; that is, each one has the

Fig. 10.—Upright Class B globe.

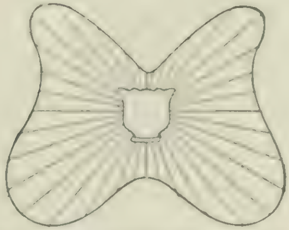

Fig. 11.—Characteristic distribution of upright Class B globe.

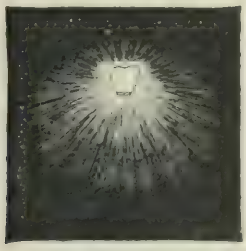

Fig. 12.—General distribution effect obtained with upright Class B globe.

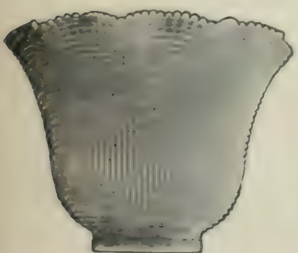

Fig. 13.—Upright Class C globe.

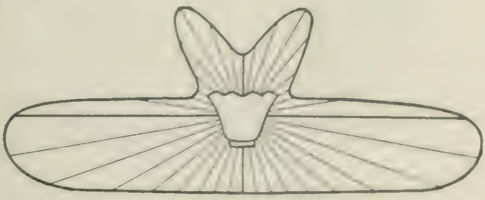

Fig. 14.—Characteristic distribution of upright Class C globe.

Fig. 15.—General distribution effect obtained with upright Class C globe

long straight surface underneath and the multiple faces on top; that class B globes have the prisms gradually diminishing in size until they almost disappear, and then begin again slightly near the bottom of the globe; that class C globes have the same characteristics as class B, except the lower prisms slope in the opposite direction from the upper prisms, thereby throwing the light from these lower prisms more upward.

HOW TO TELL PENDANTS FROM UPRIGHTS.

From the illustrations in fig. 16, and also fig. 4, it will be noted that the light is largely thrown from the long flat sur-

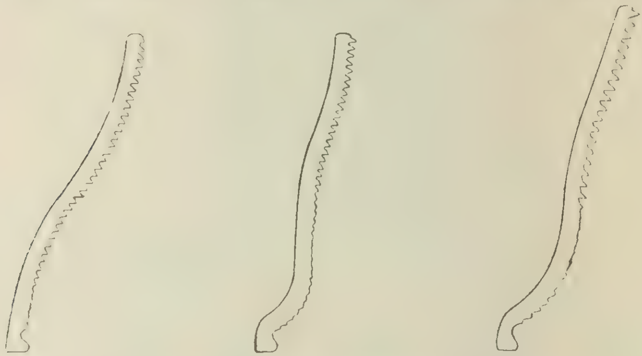

Fig. 16.—Indicating general formation of external prisms for Classes A, B and C.

face. This surface must always point downward. Hold the globe up to the light, so as to look across the prisms, and use the globe so that this long, straight surface will be down. Another simple method is to run the thumb-nail up and down the globe One way it will slip over the prisms easily, and the other catch on the long, straight surface. If the nail catches in running away from the neck, it is an upright; while if it catches going toward the neck, it is a pendant.

MODIFICATIONS.

It is recommended that a single illuminant of the proper size be placed within prismatic hemispheres and spheres rather than to employ two, three or more lamps. Where one illuminant is used no obstruction is offered to the light rays which directly strike the surface of the redirecting and diffusing envelopes.

Where more than one lamp is used, an absorption usually approximating about fifteen per cent. results, due to the in-

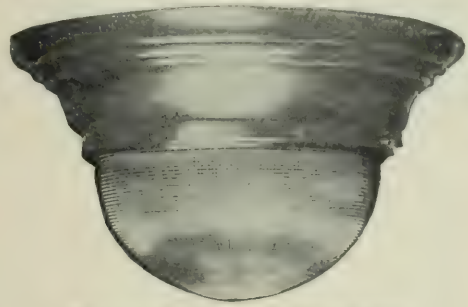

Fig. 17.—Pendant prismatic hemisphere.

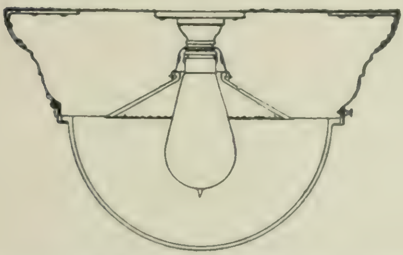

Fig. 18.—Cross section, showing mounting of single lamp in pendant prismatic hemisphere.

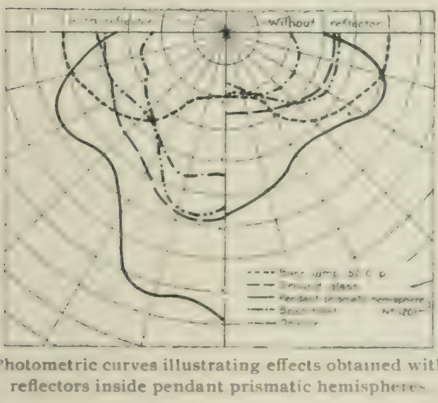

Fig. 19.—Photometric curves illustrating effects obtained with different reflectors inside pendant prismatic hemispheres.

terference of light rays by other lamps. The absorption due to such interference increases as the lamps blacken or become covered with foreign matter.

Prismatic glass globes, and for that matter practically all other kinds of glass globes, show to a better advantage when a single illuminant is placed therein than when several lamps are used; for where a number of lamps are employed they are oftentimes placed so close to the envelope that "spots" of light are, to a greater or lesser extent, visible, resulting in imperfect diffusion and unsymmetrical and inartistic effects.

From a study of photometric curves shown in fig. 19 it will be noted that practically any distribution of light may be obtained from scientifically designed prismatic hemispheres and spheres through the use of various reflectors placed above the lamps, as indicated in fig. 18. Where it is impractical to use a scientifically designed prismatic reflector in a hemisphere, it is recommended that a white, asbestos disk be placed so that it will rest on the

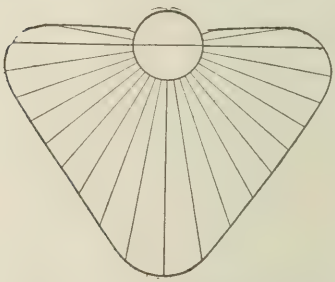

Fig. 20.—Characteristic photometric distribution with single light equipment.

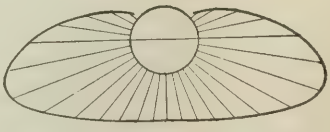

Fig. 21.—Characteristic photometric distribution equipped with cluster of lamps.

flange of the hemisphere directly over the lamps. This disk will not only assist in redirecting light rays, which otherwise would be largely lost, but also serves to prevent dust from falling on the inner surface of the hemisphere.

PRISMATIC REFLECTORS—(CLASS NO. 2).

The construction of prismatic reflectors is different than that of prismatic globes. Generally speaking, the interior surface of these reflectors is smooth; while the outer surface consists of right-angled prisms designed to reflect the light.

It is evident from fig. 29 that a ray 1 2 will be doubly reflected from the right-angled prisms, but that rays 5 6 and 7 8, which strike at right angles to the surface, will pass directly through

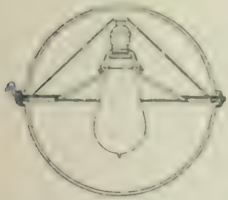

Fig. 22.—Diagram showing method of mounting a single lamp and reflector inside of prismatic sphere.

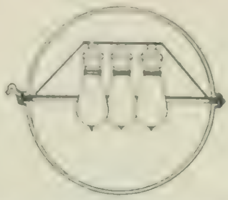

Fig. 23.—Diagram showing method mounting a cluster of lamps inside of pendant prismatic sphere.

Fig. 24.—Pendant prismatic sphere.

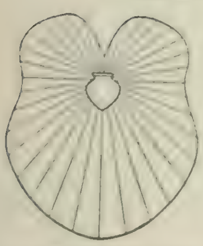

Fig. 25.—Characteristic distribution of all short stalactites with one exception.

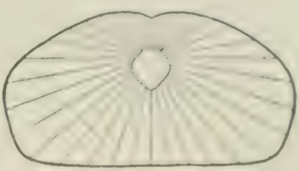

Fig. 26.—The exception.

the glass; so that a reflector will not appear totally dark, but will allow sufficient light to pass through so as not to cast shadows on the ceiling. This effect alone, namely, of being able to make

Fig. 27.—Prismatic upright ball.

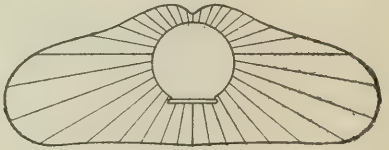

Fig. 28 —Characteristic distribution of prismatic upright ball.

an efficient reflector without casting shadows on the ceiling, marks a valuable step in advance over ordinary reflectors; but when combined with this it is possible to efficiently redirect the rays of light in any direction, by properly shaped reflectors

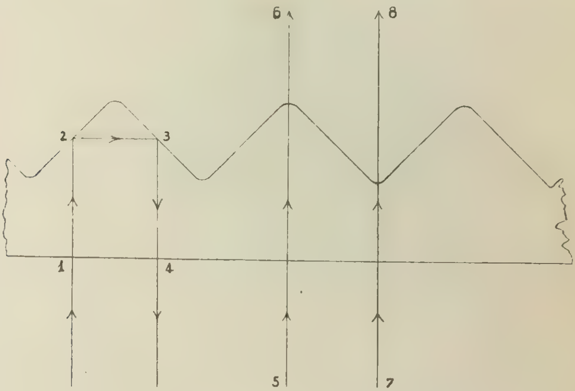

Fig. 29.—Showing principle of prismatic reflector.

and prisms, a valuable adjunct is available to those having to do with the design of lighting systems. These reflectors are made of the same grade of glass, having an especially high index of refraction, as is used in the manufacture of the globes previously described.

In order to overcome glare and to provide a "soft," agreeable illumination to the eye, the Holophane Company, after extended experiments, has developed what is termed a "satin finish," which is given to the inner or smooth surface of the reflector. Through the employment of this finish, not only is a high degree of diffusion obtained, but a rich appearance that is most pleasing is given to the reflector.

With the use of satin finished reflectors, the efficiency as measured in purely physical terms is, perhaps, five to ten per cent. less than that obtained with clear reflectors; yet the "visualizing efficiency" is higher, in most cases where the lighting units are within easy range of vision, because the eye is enabled to properly perform its functions in the absence of glare. This value, together with the pleasing effects obtained through the use of satin finished reflectors, more than offsets the decrease in what might be termed physical efficiency.

DISTRIBUTIONS.

As in the case of globes afore described, prismatic reflectors, in so far as re-distribution of light is concerned, are divided into three general classes, each of which class has numerous modifications, especially designed to suit certain requirements. The three principle classes are, extensive, intensive and focusing types, usually designated by the letters I, E, and F.

Fig. 30.—Extensive type prismatic reflector.

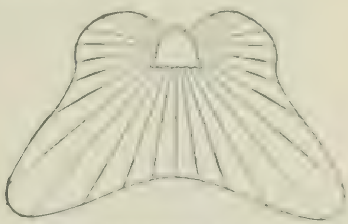

Fig. 31.—Characteristic distribution of prismatic extensive type reflectors.

The extensive type shown above gives, as the name and curves indicate, a wide, extensive distribution of light.[3] In general, the end-on candle-power is equal to approximately the rated horizontal candle-power of the lamp. With a single unit comparatively large areas may be uniformly illuminated.

[3] Frosted tip lamps are employed in all photometric tests, unless otherwise stated.

The intensive type reflector gives a distribution which is not as broad as the extensive, and not as concentrating as the focusing type. The end-on candle-power usually approximates two and

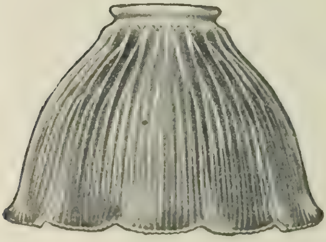

Fig. 32.—Intensive type prismatic reflector.

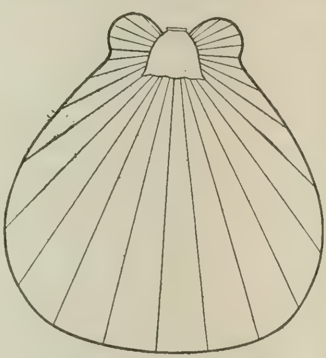

Fig. 33.—Characteristic distribution of prismatic intensive type reflector.

one-half times the rated horizontal candle-power of the lamp. This type is designed, primarily, for lighting large rooms by means of distributed units placed in the form of squares and is, perhaps, the most generally useful reflector available.

Fig. 34.—Focusing type prismatic reflector.

Fig. 35.—Characteristic distribution of prismatic focusing type reflector.

The focusing type reflectors (fig. 34) are designed for the average place where fairly strong concentration is desired. The end-on candle-power usually approximates four times the rated horizontal candle-power of the lamp. Where specially concen-

trating results are required, the powerful concentrating types, later on described, should be employed.

Figs. 36, 37, 38 and 39 illustrate various prismatic formations as applied to reflectors in this system. Upon referring to fig. 36, it will be noted that these "stilleto" prisms near the tops or necks of the reflectors are larger than they are at the bottom, also that there are more prisms at the bases or bottoms of the reflectors than there are at the top. In general shape these prisms are somewhat comparable to a stilleto. The stilleto prisms mark the most recent development of prismatic formation. They are

Fig. 36.—Stilleto.

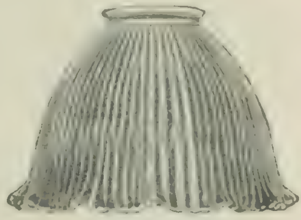

Fig. 37.—Merged.

Fig. 38.—Equal.

Fig. 39.—Continuous.

more efficient than other prismatic formations shown above. Through the employment of the stilleto prism not only is greater efficiency obtained, but lightness, weighable and visible, which are practically and artistically desirable. Fig. 37 illustrates a previous development to obtain higher efficiency and attractive effects. Fig. 38 illustrates the "equal" type, consisting of three bands of prisms, so arranged that each succeeding band, from the top (neck) to the bottom, has a greater number of prisms than the preceding band. Through such construction the prisms are made of a size and shape which will afford high efficiency. Fig. 39 illustrates the "continuous" prismatic formation as associated

with early developments. It will be noted that the prisms in the continuous type are naturally smaller at the top, near the neck, and larger at the bottom. Where prisms become so small near the top of the reflector as to lose their efficiency, as far as redirecting the light in useful directions is concerned, advantage is taken of the principles incorporated in class I, and a neck or collar is formed in the glass, having both internal and external prisms which allow the light to pass through the glass and from there is thrown to a predetermined angle. In this way higher efficiency is obtained.

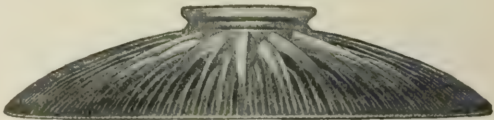

Fig. 40.—Prismatic reflector designed for meridian or round lamps.

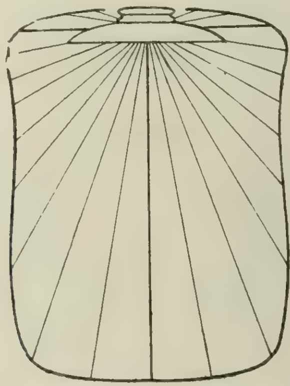

Fig. 41.—Characteristic distribution of reflector for meridian lamps.

The reflector shown in fig. 40 was designed for meridian or round lamps. It gives a very distinctive appearance, as well as high efficiency. Bowl frosted lamps should always be used with reflectors of this type. It will be noted that these reflectors give a somewhat different distribution from the three types previously described.

The type of reflector shown in fig. 42 represents the most practical reflector obtainable where strong concentration of light is desired; at the same time it permits a certain amount of light to pass above the horizontal, illuminating the upper portions of

space in which it is placed. With this type of reflector an end-on candle-power of approximately eight times the rated horizontal candle-power of the lamp is obtained.

The reflector illustrated in fig. 44 is for upright lamps. It rests directly on the bulb as indicated in fig. 45. The reflectors

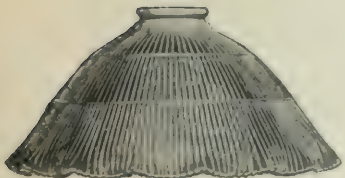

Fig. 42.—Prismatic concentrating reflector.

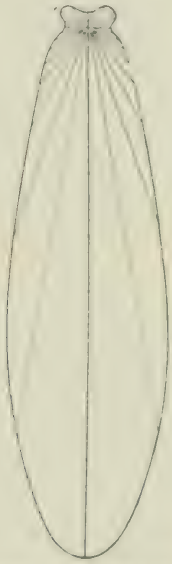

Fig. 43.—Characteristic distribution of prismatic concentrating reflector.

of this type are made to fit securely, so that no holders are required. Clear lamps should usually be used.

DECORATIVE REFLECTORS.

Inasmuch as in numerous lighting installations the esthetic takes precedence over the purely physical, it was but natural that glassware suitable to these as well as utilitarian conditions should be developed. In obtaining artistic designs certain losses in physical efficiency usually result; these, however, are more than compensated for by the pleasing effects obtained. The following few illustrations (figs. 47 to 59) of this one of the latest developments which, while being representative of some designs now available, is not to be considered as a "catalog presentation." They are shown here merely to indicate lines of

development rather than to specifically illustrate all designs now available. The designs shown should not be considered as rep-

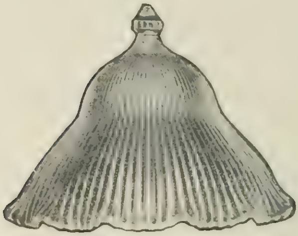

Fig. 44.—Prismatic pendant reflector to fit on upright lamp.

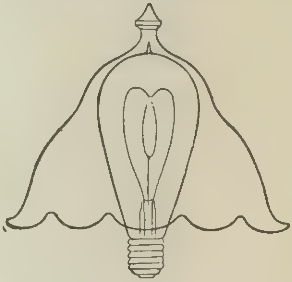

Fig. 45.—Diagram showing how this type of pendant reflector fits over upright lamp.

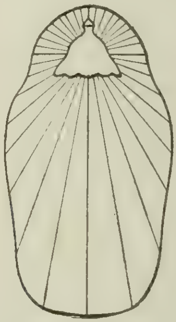

Fig. 46.—Characteristic distribution obtained from such combination.

Fig. 47.—Prismatic decorative reflector giving symmetrical distribution.

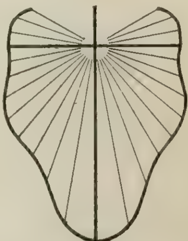

Fig. 48.—Characteristic photometric curve of this reflector.

resenting the "last word," but rather the beginning of a development which will rapidly expand and becomes the more satisfactory as it progresses.

Fig. 49.—Prismatic decorative reflector giving symmetrical distribution.

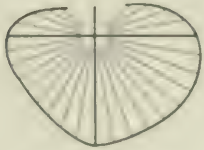

Fig. 50.—Characteristic photometric curve of this reflector.

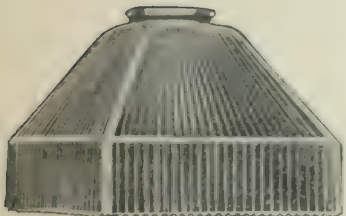

Fig. 51.—Prismatic decorative reflector.

Fig. 52.—Prismatic decorative reflector.

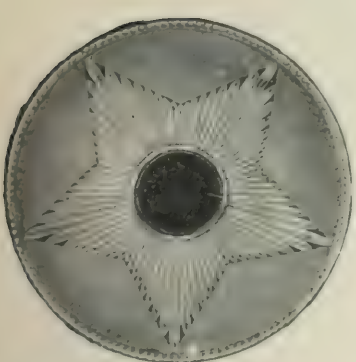

Fig. 53.—Prismatic decorative reflector.

Fig. 54.—Prismatic decorative reflector.

SPECIAL.

This reflector consists of a secondary prismatic plate, as shown in fig. 59, which forms a partial bottom to the reflector proper, and contains an opening into which the lamp bulb fits snug-

Fig. 55.—Prismatic decorative reflector.

Fig. 56.—Prismatic decorative reflector.

Fig. 57.—Prismatic decorative reflector.

Fig. 58.—Prismatic decorative reflector.

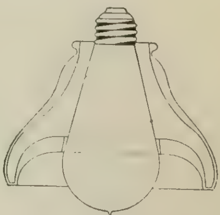

Fig. 59.—Construction of this reflector.

ly. The reflector is both pleasing and efficient. When the reflector is hung at an angle, the prismatic plate should be satin finished, unless it is placed at some considerable distance from the eye so as to avoid any glare. When it is to hang straight—

pendant—a clear, prismatic plate should be used. The reflector proper is always supplied in clear glass.

In fig. 60 is illustrated a prismatic reflector in combination

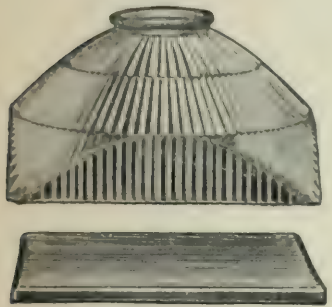

Fig. 60.—Prismatic reflector with detachable plate.

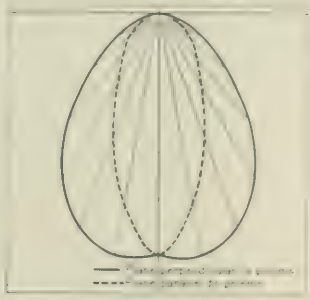

Fig. 61.—Characteristic distribution of this unit.

Fig. 62.—Characteristic distribution of type

with a prismatic plate, which unit is designed to give practically any distribution desired, as indicated in figures 61, 62 and 63 This unit was designed primarily for use in railway cars where it is placed on the under-deck of the ceiling. With this com-

bination it is possible to remove any objectionable glare and illuminate the lower portions of the car to the intensity and dis-

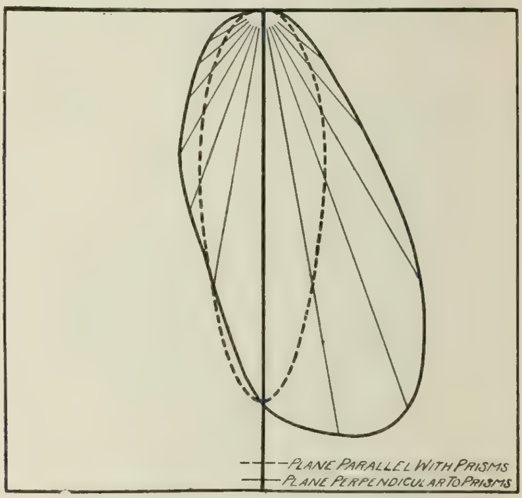

Fig. 63.—Characteristic distribution of type.

tribution desired. The principle herewith illustrated is applicable to many other classes of interiors.

REFLECTOR FIXTURE COMBINATIONS.

Prismatic reflectors are used in connection with a number of different types of specially designed units—these units, of

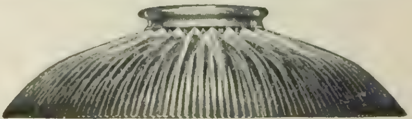

Fig. 64.—Distributing reflector for multiple clusters.

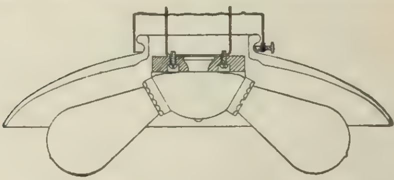

Fig. 65.—Showing use of these reflectors with wireless cluster.

course, do not include the combination of reflectors with ordinary types of lighting fixtures—two of which are illustrated in figs. 64 to 68.

In the Holophane "arc" each lamp is equipped with an individual reflector which permits of higher efficiency in effective illumination, than where a cluster of bare lamps are placed beneath a

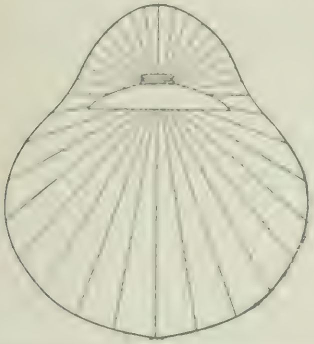

Fig. 66.—Characteristic distribution given from such unit.

Fig. 67.—Holophane arc.

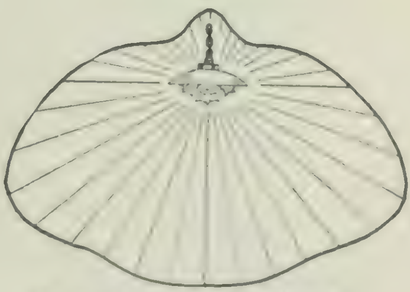

Fig. 68.—Characteristic distribution of holophane arc.

single reflector. These arcs are available in four, five and six lights, and are adaptable to all forms and sizes of lamps.

SATIN FINISH.

This finish, which has been developed after extended experiments, has been mentioned as lending a "soft," agreeable

effect when applied to reflectors. This finish enables a high degree of diffusion to be obtained with a small loss in absorption. The effect of satin finish on photometric results is generally to round out the curves.

THE VALUE OF SCIENTIFICALLY DESIGNED PRISMS.

It is doubtful if the true value of scientifically designed prisms constructed of glass having a high index of refraction is generally appreciated.

Fig. 69 shows distribution of light made possible through the employment of a scientifically designed prismatic reflector, while

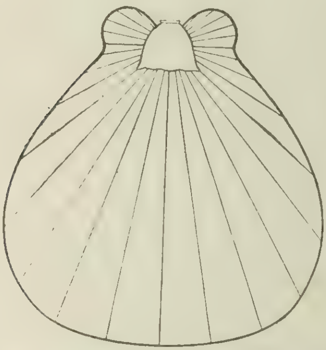

Fig. 69.—Curve obtained from intensive prismatic reflector.

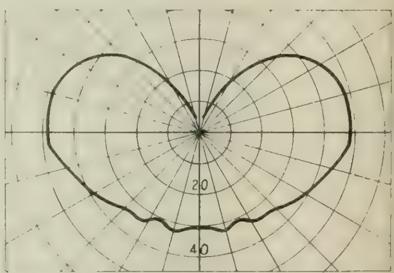

Fig. 70.—Curve obtained from clear, plain glass shade of the same size and shape from which curve in fig. 69 was obtained.

fig. 70 represents a curve obtained from a piece of glass of shape and size identical with the reflector from which the curves shown in fig. 69 were obtained; but it had not any prisms. These two curves represent two extremes. Reflectors using uncalculated or incorrectly designed prisms made of glass having a low index of refraction give effects between these extremes.

HOLDERS.

It is necessary that the proper holders be used in connection with glassware and illuminants, for if the wrong holders are employed very much different results than those calculated may be obtained. The effect of the two holder positions is shown in fig. 71.

The four holders shown in figs. 72, 73, 74 and 75 are used primarily with prismatic reflectors and for that reason are included in the section dealing with class No. 2 reflectors.

EFFECT OF DUST ON REFLECTORS.

As is the case with all forms of reflectors, it is necessary to keep the inside of prismatic reflectors clean if economic maintenance is to be effected. This operation is a comparatively simple matter, inasmuch as one has to deal with perfectly smooth surfaces. The exterior surface of a prismatic reflector naturally

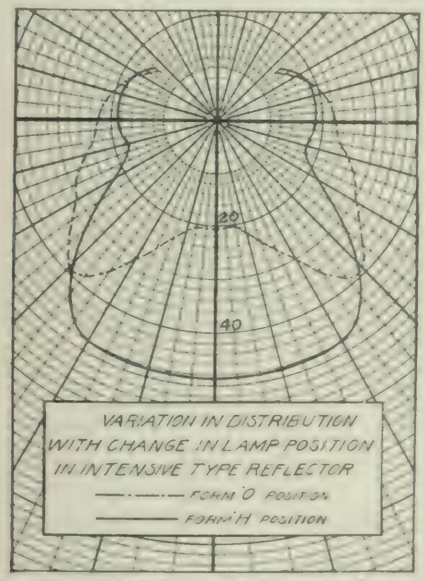

Fig. [illegible].—Results of Form O and H holders with same reflector and same lamp.

forms a place for dust or dirt to collect. Such accumulation, however, does not necessarily greatly decrease its reflecting power; it affects principally the light which otherwise passes from the reflector to the ceiling. This is due to the fact that the prisms act by total reflection, and that inasmuch as, generally, each particle of dust is surrounded by a microscopical film of air, the dust does not usually come in optical contact with the surface of the glass; so that there still remains a difference in density between glass and air, the critical angle being unchanged.

While loss of light due to accumulation of dust on prismatic reflectors is considerably less than is understood in some circles,

yet too much stress cannot be laid upon the desirability of keeping these reflectors, as well as all other makes of lighting glassware, clean. Such cleaning should include lamps. This becomes the more evident when it is realized that cleaning, which can be done at comparatively small expenditure, affects the maintenance of a lighting installation. It is strange, that while much thought and energy is expended in cleaning windows, in order to allow the passage of natural light, costing comparatively

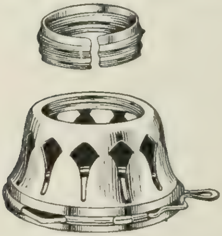

Fig. 72.—Form H holder.

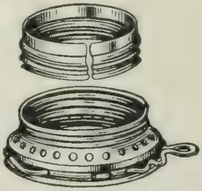

Fig. 73.—Form T holder.

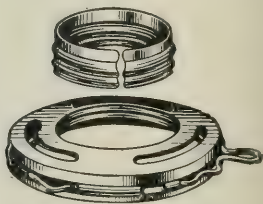

Fig. 74.—Form O holder

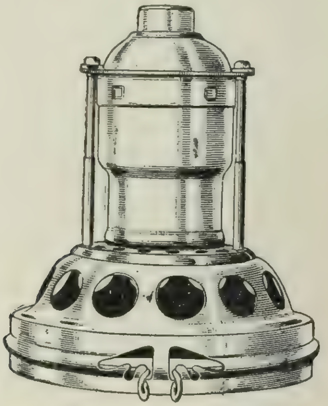

Fig. 75.—Form A holder.

nothing, little attention is given to glassware used with artificial illuminants maintained at a large expense.

It should be generally known that the special glass employed in prismatic globes and reflectors, owing to its absence of color, affords but a neutral background for dirt; and dirt is, therefore, not so readily observed as would be the case if the background were distinctive; so that dust or dirt is less in evidence on this type of reflector than might be supposed at first thought. This, however, is no excuse for permitting an excess of foreign matter to accumulate.

COMBINATION OF CLASSES 1 AND 2 (CLASS 3A).

The reflectors globes shown in figs. 76 and 78 are designed to give an irregular distribution of light, as indicated by the photometric curves of figs. 77 and 79. When used in connection with side wall brackets, they re-distribute the greater part of the light out into the room, away from the wall. In a globe that gives a symmetrical or regular distribution about its vertical axis, just as much light is directed toward the side wall as is thrown out

Fig. 76.—Prismatic asymmetrical upright reflector globe.

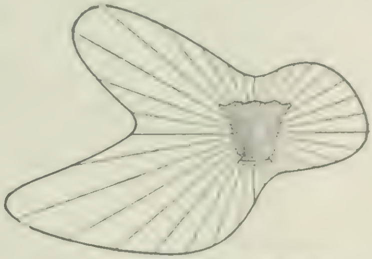

Fig. 77.—Characteristic distribution of prismatic asymmetrical upright reflector globe.

Fig. 78.—Prismatic asymmetrical pendant reflector globe.

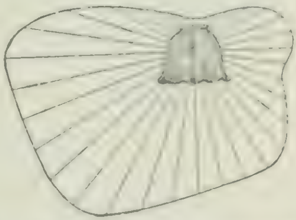

Fig. 79.—Characteristic distribution of prismatic asymmetrical pendant reflector globe.

into the room with resultant loss. This is especially so when the side wall is covered with a dark, highly absorbing paper. This principle of prismatic construction is incorporated in other designs which are adaptable to other than side wall uses. It will be noted that these reflector globes are in one piece.

The unit shown in fig. 80 consists of a prismatic reflector (class 2) and a prismatic hemisphere (class 1) which combination, as illustrated in fig. 82, gives a broad generally downward

distribution of light, and also diffusion with low absorption. The fixture indicated is but a suggestion or mechanical skeleton

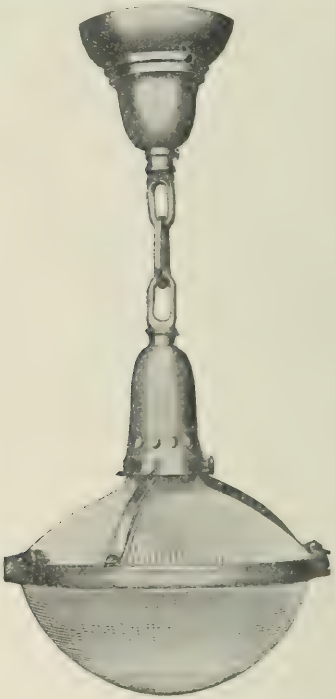

Fig. 80.—Prismatic reflector bowl.

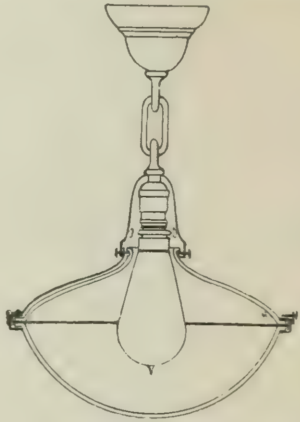

Fig. 81.—Interior arrangement of suspension fixture for prismatic reflector bowl.

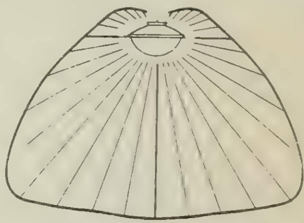

Fig. 82.—Characteristic distribution given by prismatic reflector bowl.

showing suspension. It is susceptible to treatment which will conform to various classes of interiors.

COMBINATION OF CLASSES 1 AND 2 WITH OTHER GLASSWARE (CLASS 4A).

In fig. 83 is illustrated a prismatic hemisphere with cut glass bottom. The cut glass portion of the hemisphere represents, approximately, one-third of its height, the remaining part being given over to external and internal, diffusing and redirecting prisms. The pattern shown here is but indicative of what can be accomplished in design. The cuttings, usually, are especially made to suit exacting requirements. While giv-

ing the effect of cut glass, these hemispheres still possess the properties of diffusion and redirection of light in useful di-

Fig 83.—Prismatic hemisphere with cut glass bottom

rections. Patterns, somewhat similar to that indicated in fig 83 are available in pressed instead of cut glass.

(CLASS 4B.)

The balls represented by fig. 84 are made in two parts, a plain glass ball, the bottom of which is satin finished, and a

Fig 84.—Prismatic two-piece reflector ball

prismatic reflector (class 2) which fit together, giving the same effect as the one-piece reflector balls which are made in smaller sizes. The reflector ball is manufactured in ten, twelve and fourteen-inch sizes.

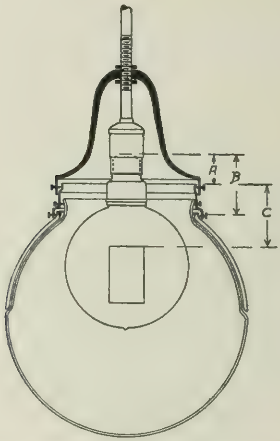

Fig. 85.—Section through prismatic reflector ball indicating lamp filament positions.

TABLE I.—RESULTS OBTAINED FROM DIFFERENT FILAMENT POSITIONS IN REFLECTOR BALLS.

Reflector	Lamp	Distribution	Contact point to top of holder A	Contact point to top of reflector B	Top of reflector to top filament C
9,814	400 watt	F	2 15/16 in.	4 5/8 in.	5/8 in.
9,814	400 watt	I	1 9/16 in.	3 1/4 in.	2 in.
9,814	400 watt	E	1/16 in.	1 3/4 in.	3 1/2 in.
9,612	250 watt	F	2 29/32 in.	4 5/32 in.	13/32 in.
9,612	250 watt	I	1 21/32 in.	2 29/32 in.	1 21/32 in.
9,612	250 watt	E	9/32 in.	1 17/32 in.	3 1/32 in.
9,510	100 watt	F	1 3/4 in.	2 7/8 in.	1/4 in.
9,510	100 watt	I	3/4 in.	1 7/8 in.	1 1/4 in.
9,510	100 watt	E	Top of metal holder 3/8 in. above contact pt.	3/4 in.	2 3/9 in.

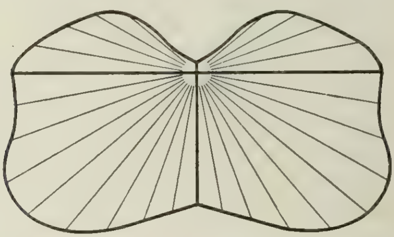

Fig. 86.—Extensive (E) curve from prismatic reflector ball.

The globes and reflectors treated within this paper are designed to give definite results. It is essential that the illuminant should bear the correct relative position to redirecting and diffusing surfaces. Fig. 85 shows in cross section the relation of the lamp filament to the inner surface of the reflector ball. In table No. 1 is shown the character of distribution, shown by E, I and

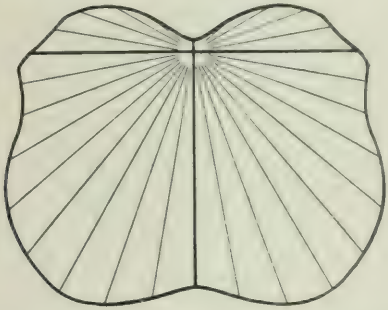

Fig. 87.—Intensive (I) curve from prismatic reflector ball.

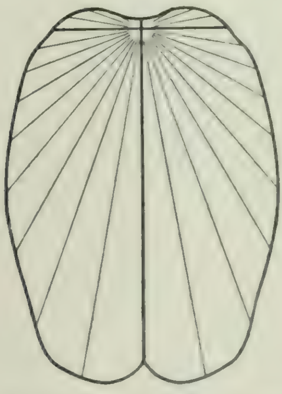

Fig. 88.—Focusing (F) curve from prismatic reflector ball.

F (extensive, intensive and focusing reflectors) obtained with the filament in specified locations, which effects are further illustrated in figs. 86, 87 and 88.

In fig. 89 is illustrated a one-piece reflector ball with cut glass bottom. The upper exterior half of these balls consists of a series of totally reflecting prisms, as described in class 2, while the lower half consists of plain glass, which is first satin finished and then cut to any desired pattern.

CLASS 4C.

As a result of a very extended[1] investigation, wherein the physiological, psychological and esthetic features, as well as the physical, were considered, the unit illustrated in fig. 90 has been developed. This unit consists of an especially designed prismatic reflector over which is placed, as indicated in fig. 91, a milk (opal)

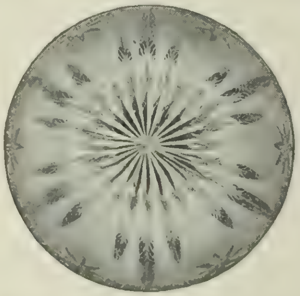

Fig. 89.—Prismatic one-piece reflector ball.

Fig. 90.—Street lighting unit.

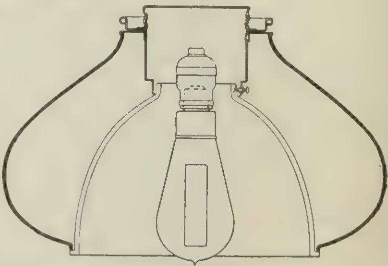

Fig. 91.—Diagram showing construction of this unit.

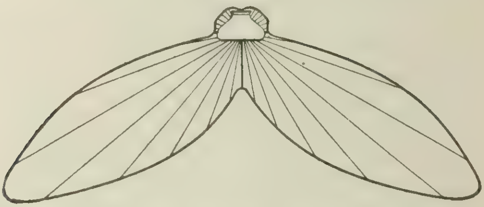

Fig. 92.—Characteristic distribution obtained from this unit.

or tinted envelope. The envelope serves to prevent dust from accumulating on the exterior of the reflector and to further soften or diffuse the light over and above the horizontal, also to effect artistic treatment. The specially designed prismatic re-

[1] An Analysis of Illumination Requirements in Street Lighting, by A. J. Sweet, *Journal of the Franklin Institute*, May, 1910.

flector previously referred to gives a very remarkable curve, which is shown in fig. 92. The greater percentage of light, it will be observed, is thrown below the angle of sixty degrees; so that practically all the light is employed in the actual illumination of the streets. This reflector eliminates not only the bright spot, usually so easily noticed about the base of a lamp post, but likewise utilizes to a high degree of efficiency the light emanating from the radiator. These units, as is the case with other developments, are specially designed to suit certain exacting requirements, and a number of these street lighting units have been developed for different sizes of lamps, mounting heights and spaces.

MANUFACTURE.

A brief description of the process of manufacture of prismatic glass globes and reflectors is probably in order. These globes and reflectors have as their inception some condition requiring certain definite treatment, which gives rise to a carefully planned and executed investigation, the results of which form the basis of design. After the design has been executed, which is by no means a matter of small import, for it has to meet many exacting requirements, it is passed on to the mold shop, where it is turned over to the pattern maker. In the case of prismatic globes having both internal and external prisms (class 1) a small section of the external or horizontal prisms is photographed directly on a steel plate to correct size. This plate is then carefully covered with wax, with the exception of the edges where the teeth or prisms appear, which are left free, and which by means of a powerful acid is eaten slightly away, forming a sharp edge. The tool is then put in the hands of an expert, and by means of hand filing the teeth are accurately cut. This may take weeks to accomplish, and one slip of a file will render the whole work useless. This forms the master tool, and from the master tool is made the cutting tool which is placed in a lathe to cut the cast steel molds. The internal prisms are formed by a plunger whose process of manufacture is much like that outlined above.

In the case of prismatic reflectors (class 2) there is a series of external, vertical prisms, and a smooth inner surface. The external prisms are cut much in the same way as the internal

prisms are cut on the plunger which forms the prisms on the inner surface of a prismatic globe, having both external (horizontal) and internal (vertical) prisms. A smooth plunger is used, whose shape and size conforms to the contour of the mold in which are cut the external prisms, for actually pressing the reflector.

Coming to the actual process of manufacture: the glass, in a semi-molten state, is dropped into the mold, the exact amount each time being carefully calculated, so that there will be neither excess nor lack of material. The plunger, operated in some cases by a steam press, is then brought down into the mold, pressing the glass into its shape. The mold, which is in four pieces, is then opened and the glass carefully taken out and placed in a holding tool, with which it is placed in the fire-polishing furnace. After being duly fire-polished, it is brought out again, and in the hands of an expert workman it receives its final shape, crimping, etc. It is then ready for the annealing oven, going through different gradations of temperature so as to be thoroughly annealed. Coming from the annealing oven, the glass is placed on the grinding wheels, and all rough surfaces on the collars are ground away. The glass is then carefully washed and wrapped in paper to protect it from dust and chipping. It is then ready to be packed.

In all these processes, the utmost care must be taken to obtain absolute accuracy. Wherever this accuracy is not had the results are entirely different from those calculated and occasion a loss.

After a mold has been used it is returned to the tool-room and carefully cleaned with emery and oil. Although this is done with great care, the mold wears slightly; so that after a number of turns the mold must be destroyed and a new one made, if accurate results are to be obtained. To the ordinary observer, globes made from a worn mold look like ones where the prisms are sharp, but the results are far different in the light-giving qualities. Absolute uniformity and accuracy are the watchwords in the manufacture of all such globes and reflectors if the desired results are to be obtained.

PART III.

BY L. W. YOUNG.

This part of the symposium deals in a general way with the requirements of modern illumination glassware. It sets forth the characteristics of a single brand of such glassware known in trade by the name Alba. For convenience in presentation of this paper, glassware is divided into three classes (1) commercial shades, (2) ball globes, spheres and stalactites, (3) bowls, urns and similar decorative pieces and special shapes.

Though similar in some respects, there are distinctive requirements for the glassware of each of the latter three classes. Shades need primarily the qualities of reflection in order to be normally efficient, and secondly the properties of diffusion to make reflection uniform and smooth and to give that decorative beauty which causes them to be unconsciously gratifying to the senses. Ball globes and spheres need qualities of translucency without selective absorption which would cause the distortion of the true color of the light source; low absolute absorption, meaning good efficiency, other things being equal; and good diffusion to allow the whole globe to become a source of light. Decorative pieces are not designed to be primarily efficient, hence the requirements are principally attractive design and color, good diffusion and a composition and structure which will either allow the glass to assume the color of the light source, or else give it certain definite properties identical with those of high selective absorption.

The composition of this glass is peculiar. When endeavors were being directed towards producing a pure white diffusing glass of superior character, it was noted that such a glass must fill the following requirements. It must have a universal "daylight" color, hence be white. It must possess the powers of diffusion as an original property, as distinguished from glassware which is made non-transparent by some roughing treatment. It must possess a minimum of selective absorption to appear white in commercial use if the source be white, or in residence use to appear colored like the source

may be colored. It must possess a minimum of absolute or total absorption which usually is contradictory to good diffusion, meaning that a careful balance must be determined between these two qualities. It must have properties of reflection to be useful as a reflector, and yet not sacrifice for pure reflection those qualities which please the physical senses. It must have a low coefficient of expansion to provide for fittings to metal, not fragile, and be able to resist heat. To just what extent such glass should possess certain other refined characteristics such as properties of the absorption of ultra-violet rays and fluorescence has not been definitely determined. However in the glass under consideration it is fairly evident that some fluorescence does occur, which argues for efficiency in conjunction with light-sources of an over-abundance of short wave-lengths.

The chemical composition of this glass and its physical characteristics are unique in several respects. It seems to most nearly fulfil the aforementioned requisites. It is of a clear or crystal base, holding in itself by a species of colloidal suspension a very great number of infinitesimal flakes. These flakes act to give color to the glass, to break up the rays of light and to aid in reflection of light. This glass is entirely distinctive from the so-called "milk" or opal glasses, which reflect largely from the surface and are highly absorbent, both absolute and selective.

The features or advantages claimed for it by its manufacturer are as follows. (1) Good reflection, (2) partially controllable reflection, (3) partially diffuse reflection, (4) efficient transmission, (5) true-color transmission, (6) diffuse transmission, (7) cleanliness and permanency, (8) excellent physiological effects aiding in conservation of vision, (9) possible advantageous physical properties of ultra-violet absorption and of fluorescence, (10) artistic effects capable of being produced in both design and color, (11) ability to assume the color of the light source, (12) general balance of diffusion transmission and reflection of light.

To the foregoing statements a few supplementary notes seem necessary. Unlike sand-blasted shades the distribution curves of Alba shades shows a consistently good proportion of flux in the lower hemisphere, that is from shades designed for such distribution. The range of reflection of four typical distribution curves

of such shades (fig. 1) shows the range over which reflection can normally be varied, and indicates the latitude of selection of shades at the disposal of the illuminating engineer.

The question of efficient transmission can be answered best by means of comparative tests upon totally enclosing spheres or ball globes. Typical distribution curves of globes such as are used principally in decorative tungsten lamp boulevard lighting are shown in fig. 2 and from the data of this same test the following figures on total absorption have been compiled: standard crystal roughed inside globe when new and clean 16.75 per cent.; thin

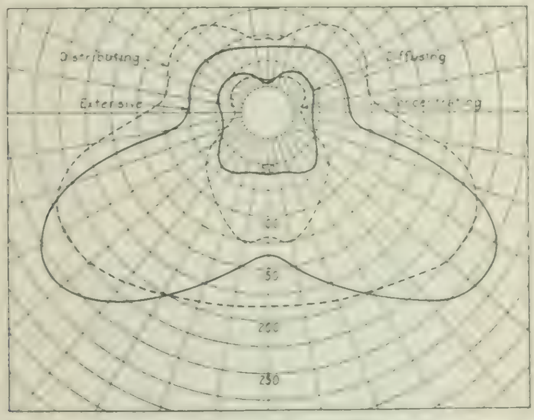

Fig. 1. Four typical curves of light distribution from Alba shades.

opalescent 15 per cent; regular Alba 13.5 per cent. The size of globes used in the test was 10 inches; the source of light was a 60-watt series tungsten lamp burning on high efficiency rating. The globes which were tested are shown in fig. 3. Here should be noted the lack of diffusing powers of crystal roughed wares as evinced by a similarity between the curve of the bare lamp and the lamp when equipped with this kind of globe. Also it need hardly be stated that constant collection and absorption of dirt materially increased the absorption of crystal roughed globe, and that the absorption in opalescent globes is a question of the thickness of the layer or "casing" of dense opal glass which in conjunction with one or more layers of clear glass forms the walls of such globes.

Diffuse reflection and transmission are properties very diffi-

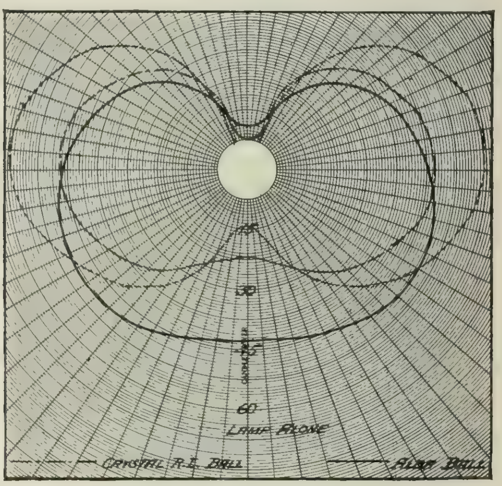

Fig. 2.—Typical distribution curves from globes used with tungsten lamps in boulevard lighting.

Fig. 3.—Type of globe used in tungsten lamp boulevard lighting (see Fig 2).

cult of experimental determination and their proof is and must be the absence of glare or the sense of fullness and satisfaction

left—perhaps unconsciously—in the mind of the observer. Concerning the reflection from the inner surface of an Alba shade the results of comparative tests made upon two types of shades (fig. 4) whose distribution curves have been determined first

Fig. 4. Two typical shades for interior lighting

with the regular surface and, second, with the inner surface frosted (fig. 5 and fig. 6) should be noted. There is a surprisingly small difference. The conclusion is that the original reflection from the regular surface is considerably diffuse in char-

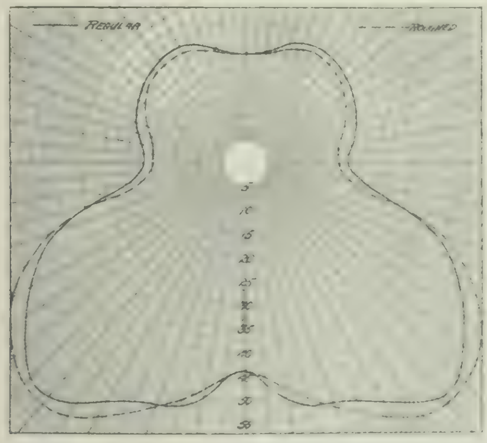

Fig. 5.—Light distribution curves from a shade with regular and frosted inner surfaces (shade shown in fig. 4)

acter or that the inner surface plays but a small part in the reflection results and that the body of the glass shade is largely concerned in the reflection. Either view would mean a softened quality of light in the regular operation of the shade.

Cleaning is a very pertinent question to be answered in any extensive installation of glassware. Research of Mr. C. E. Clewell of the Westinghouse Company and others has been di-

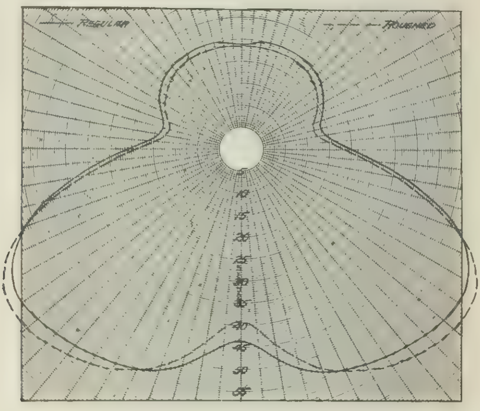

Fig. 6.—Light distribution curves from a shade with regular and frosted inner surface (shade shown in fig. 4).

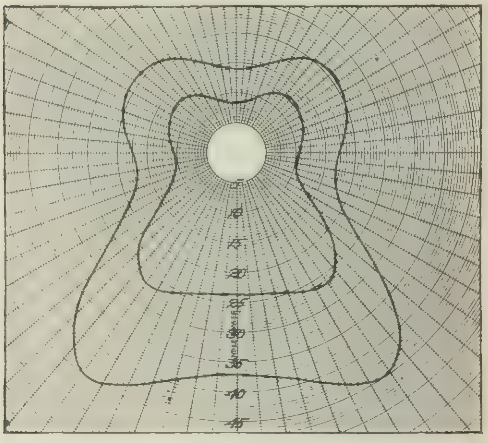

Fig. 7.—Distribution of light from a shade, showing the balance obtained between the upper and lower hemispherical flux.

rected toward this end. Naturally the most readily cleaned surface is the one which is perfectly smooth and with fewest possible ribs or crevices.

Closely connected with the question, cleaning is the consideration of breakage. This is largely a matter of moderate care: but it is also true that expansion of glass has a large effect in

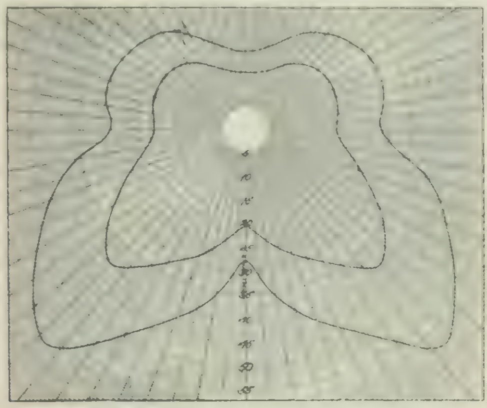

Fig. 8.—Distribution of light from a shade, showing the balance obtained between the upper and lower hemispherical flux

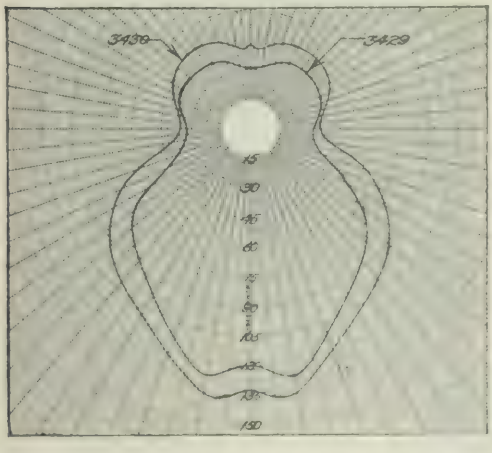

Fig. 9.—Distribution of light from a shade, showing the balance obtained between the upper and lower hemispherical flux

breakage particularly under set-screws, etc. It may be interesting to note in this connection that the coefficient of expansion for Alba glass is 0.0000067. When compared with the coefficient

0.0000056 of what is known as "high-speed" glass, which is so little affected by temperature changes as to be successfully used in gage glasses, stove door plates and the like, this low figure is somewhat remarkable. And though its coefficient is higher than that of the high speed class, it is not infrequently used in

Fig. 10.—Pendant sphere for decorative interior lighting.

the manufacture of inner globes for enclosed arc lamps. The coefficient of expansion of lime glass is 0.0000094.

The physiological and in many senses the final results are always to be considered in judging illuminating glassware. It has been said that an expert in judging the illumination looks at the object illuminated, while the novice looks at the light source. It must be admitted that both views are criteria of the true illumina-

tion in any case. If one would imitate daylight he must have a diffused light coming in general from above, and the adaptation through many generations of the eye to the light from above has led to the use of light-colored ceilings and conforming modes of interior decoration. Furthermore in artificial illumination it seems reasonable that it is a mistake from the viewpoint of physiological comfort to have heavy shadows around and

Fig. 11.—Dish shaped shade for decorative semi-indirect lighting

above the working plane, thereby attempting to make day and night illumination distinctly different. Such arguments lead to the conception of an illuminating system wherein the proportions of upward and downward light are nicely adjusted to illuminate the working plane amply and the other portions of the room less intensely. And a difference of intensity is required—whether it be from the scientist's viewpoint for the restoration of "visual purple" in the retina or from the layman's viewpoint of

merely "resting" the eyes by looking at other points than on the working plane— and just such a balance between upper and lower hemispherical flux is what has been aimed at in Alba commercial shades. The appended distribution curves, figs. 7, 8 and 9 show how this balance has been accomplished to suit general practise. Averages of the majority or regular types of

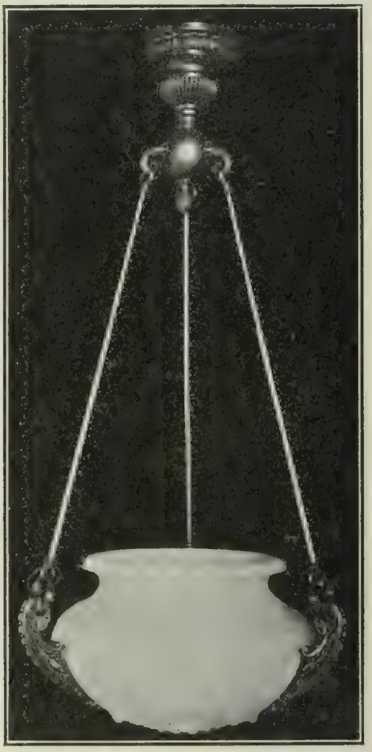

Fig. 12.—A fancy urn for decorative interior lighting.

these shades give figures of 36.9 per cent. upper and 63.1 per cent. lower flux.

Pendant spheres should be mentioned as the first prominent diffusing unit used in connection with large tungsten lamps for successful decorative interior illumination (fig. 10). No new mechanical principles are involved in these units beyond the devices of their supporting fitters and the glass being in

hemispheres giving easy access to the interiors for lamp renewals and cleaning. Photometrically these spheres overcome the grave defects of crystal roughed globes, namely, "spot" lighting and apparent distortions of the unit, which faults have been sufficiently commented upon in former issues of the TRANSACTIONS.

Artistic effects in this glass are now being obtained in a large and increasing number of special shapes. Prominent among these are dishes for semi-indirect lighting, fig. 11, one being twenty-two inches in diameter with a classic relief very typical of carved alabaster or Carrara marble and adapted for a cluster of 40- or 60-watt lamps. A large urn, fig. 12, of similar composition is used for much the same purpose. Architectural requisites can surely be met by such pieces where the decorative illumination of a large interior becomes in truth a part of the interior furnishings. Nor is the lighting efficiency at all poor since in a typical residence dining room of dark finish and mahogany furniture the results are well above two lumens per watt.

Glass plates and tile are rapidly coming into extensive use for concealed illumination notably in the tops of display windows and the domes of lobbies and auditoriums or in the forms of friezes and girandoles. In such cases a diffusing glass of low absorption is a requisite, meaning the use of as few lighting units as possible and still obtaining an apparent source with uniform intensity of radiation over its whole area. Cylinders and troughs of this glass now on the market suitable for continuous filament lamps should also find a place in many illumination specifications.

The almost infinite variety of purely decorative shades could hardly be described here. Illustrations of a few of these are given. One of the most handsome types is shown in fig. 13. These are shades in Sheffield and Art Noveau designs either fluted or elaborated with green or verde ribs and showing pink, yellow, orange, green, and irridescent colors. Particularly suitable for the illumination of a den or similar residence rooms is the class of colored wares like the one shown in fig. 14. This glassware comes in various colors: green, ruby, amber, opales-

cent. or in all such colors heterogeneously combined, and usually possesses a roughed or pitted exterior surface and is pressed in square, hexagonal, or novel shapes. Wide application is made of this glassware to electric portable lamp shades.

All these types of shades in their various styles and designs to-

Fig. 13.—Several types of artistic shades for decorative interior lighting.

gether with cut and etched frosted and sand-blasted glassware can be found to meet any normal requirement of the discriminating illuminating engineer. Such a latitude of choice means less routine and more selection on the part of the engineer and less dissatisfaction on the part of the consumer. Constant investi-

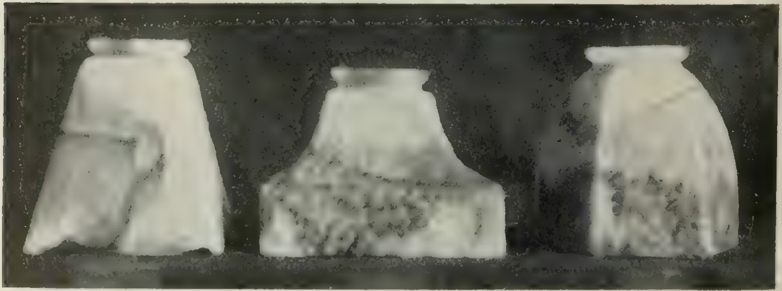

Fig. 14.—Artistic shades for den or similar interior decorative lighting.

gations in the field of illuminating glassware leading up to new glasses new shapes and new devices and bringing about new ideas of illumination must lead to the desirable attainment

of adapting artificial illumination to all the various wants of mankind. Just as these wants are becoming insistent and manifold so must illuminating glassware be given careful consideration and have a wide latitude in design and manufacture to fulfil these wants.

DISCUSSION.

Mr. Norman Macbeth:—The continued advisability of barring from our TRANSACTIONS matters leaning towards the commercial side has been a subject on which I have not always been in full agreement with other members of this society. The lines have invariably been drawn very tightly in the past and it was my impression that a judicious amount of commercialism would help the section attendance, arouse a more general interest among the bulk of the membership and would add to the value of our one very important an much appreciated contribution—the discussion. I favored permitting a writer to go as far as he liked, with the almost certain knowledge that if he couldn't be good he must at least be careful and that the greater the distance he overstepped into pure commercialism, the greater would be the drop after those members whose interest lay in the development of the society along broad lines had concluded the puncturing of the fictitious claims made purely from the standpoint of their resultant advertising value. After listening to these papers and the discussion so far presented, I am inclined to agree with the so-called conservative members who feared or foresaw the results of just such an experiment.

There are a few points to which I would like to call attention. In fig. 5 of Mr. Marshall's paper is given a diagram with two distribution curves, one of a prismatic ball globe of the manufacture approved by the writer, and the other of an imitation. On another page it is stated under "How to tell Pendants from Uprights," "If the nail catches in running away from the neck it is an upright: while if it catches going toward the neck it is a pendant." I would like to know whether this test was applied to these two balls, particularly to the imitation; because if you invert that curve, assuming that the imitation ball was an upright it proves to have a very excellent distribution.

In fig. 6 of the same paper, the photometric curves show the results on a prismatic globe clean and dusty. This diagram has been quite familiar to many readers of illuminating literature for some years, but I feel that the curve should be very positively qualified by the statement that it is of an enclosing ball globe. Many salesmen not familiar with the technical terms of the art confuse globes and reflectors. I have even known those who should be better informed to refer to this test as evidence bearing on the effect of dust on prismatic glass reflectors. The inference is decidedly improper, that a reflector may be used "for several months in a dusty place, allowing a heavy coating of dust to accumulate on its outer surface with a loss of light due to dust of only 13 per cent. almost all of which was in the light distributed above the horizontal." I may be mistaken, but it would appear to me to be of vastly greater importance had figures been given on prismatic reflectors, the output of which when compared with ball globes must be many times greater and to which a large proportion of the manufacture is undoubtedly confined. The ordinary glass reflectors, if left in a medium dusty place for that period, would show a loss of perhaps 30 to 50 per cent.

It should be emphasized on every occasion, that all reflectors, whether glass or metal, should be thoroughly cleaned regularly. The interval between cleanings is strictly dependent upon the locations where the reflectors may be installed. The interval may be that during which the loss in light, due to dust, is not exceeded in cost by the expense of a thorough cleaning.

There is another test reported here on page 866 on the absorption of scientifically designed globes, which Mr. Marshall could properly have brought up-to-date. From the foot note it would appear to be now somewhat over ten years old. At this date, we cannot well question the work done at the Massachusetts Institute of Technology, nor the result that the total loss was but 12.3 per cent. The statement on page 899 that the absorption was 13.5 per cent. with a blown Alba ball which was so quickly questioned by a previous speaker and referred to as a remarkably high efficiency, would seem to lead to a possible conclusion that the lesser loss with the prismatic globes,—not of thin blown glass, but of pressed glass which "consists of a series of vertical, in-

ternal, diffusing prisms, * * * combined with a series of external, horizontal, compound, redirecting prisms, having both refracting and reflecting faces" may be due to the assumption that the index of refraction of the glass used ten years ago was very much higher and also that the glass possessed advantages in the one particular as regards light absorption at least, to a very much greater extent than the glass which is at present available.

The results of an exceedingly interesting series of tests were given in the second paragraph on page 875, and while Mr. Marshall perhaps properly felt that it would add appreciably to the length of his paper to touch upon the details of these tests, I hope he will reconsider his decision. "With the use of satin finish reflectors the efficiency as measured in purely physical terms is, perhaps, five to ten per cent. less than that obtained with clear reflectors; yet the 'visualizing efficiency' is higher." This is a matter in which I feel we are all much interested, and I would appreciate a suggestion as to how such tests can be best conducted, also a brief description of the tests made which warranted the above conclusion.

Mr. V. R. Lansingh:—There are one or two points in Mr. Marshall's contribution I want to call attention to. If you will kindly turn to page 871 you will see a number of photometric curves. Fig. 19 shows photometric curves of a bare lamp, of a ground glass bowl, of a prismatic hemisphere, of a beaded and of an opaline bowl. The curves on the right hand side were obtained without any reflector inside the hemisphere; and on the left-hand side with the proper reflector. It seems to me that is a very valuable set of curves and shows what is possible with all kinds of hemisphere lighting simply by using a reflector inside. Nine hemispheres out of ten as mounted are not mounted with any form of reflector inside. Mr. Marshall has called attention to a white asbestos disk placed inside to increase the total flux of useful light very materially, and that is independent of the nature of the enclosing envelope used.

Mr. Marshall on another page shows a number of typical photometric curves from prismatic glass. In comparing Mr. Marshall's paper with those describing other kinds of lighting glassware, the thing which strikes one most forcibly is the flexi-

bility of the prismatic system acting as it does by specular reflection. The varied distribution curves are quite remarkable; for example, figure 43 as compared with figure 31. Figure 31 has an end-on candle-power equal to about the rated horizontal candle-power of the lamp while fig. 43 has an end-on candle-power of eight times the rated horizontal candle-power of the lamp, a ratio of eight to one.

Perhaps the worst enemy of the prismatic system is itself. By that I mean, acting as it does by specular reflection the same as mirrored reflectors, it is necessary to use it correctly in order to get predetermined results. If the filament or incandescent lamp, or mantle in the case of the gas burner, is placed in the wrong position one will not get the results which he expected; and this is clearly brought out by Mr. Marshall in figure 71. I would like those who have their papers just to note that figure. The difference between those two photometric curves is very remarkable, and yet they were obtained with the same lamp and the same reflector but in different holder positions.

As other examples of the flexibility of this system note figs. 86, 87 and 88. From a ball of the prismatic type these three different and distinct curves of distribution were obtained by placing the lamp in different positions. This may or may not be a desirable thing. If it is used correctly there is a very good means at one's disposal to get any illumination within wide range, but if put in the hands of a novice and used in any old way, obviously one may get just exactly what he doesn't want.

Mr. F. L. Godinez:—Referring to Mr. Marshall's contribution I think it is generally understood that in prismatic glass the utilization of the flux is thirty per cent. in the upper hemisphere (transmitted) and seventy per cent. below (reflected) I would like to enquire from Mr. Marshall if he can give some figures regarding the separation of that seventy per cent. reflector flux: first, what per cent. is due solely to prismatic reflection and second what per cent. is due to specular reflection from the polished surface of the glass independent of prismatic reflection? Attention is directed to the fact that the curve shown in fig. 69 is without any photometric data; also no photographs of the reflectors are shown. Comparison, is therefore impossible.

On another page Mr. Marshall has shown a cut which we have all observed quite frequently regarding the dirt effect on prismatic globes. I would like to ask if any curves have been shown indicating the depreciation of transmitted flux due to accumulated dust and dirt falling on reflectors not globes.

In figures 36 and 37 there are two types of globes indicated resembling "prisms." I would like to enquire whether these "prisms" were added for utility or grace and, if so to what extent they are efficient.

Mr. A. J. Marshall:—Referring to the discussion by Mr. Macbeth, relative to the use of glassware in a pendant or upright position, I wish to say that I have already dwelt on the fact that in glassware there is no one panacea for all lighting ills, and no one particular kind of glassware that gives thorough satisfaction for every condition. In answer to Mr. Macbeth's question I wish to state that the globe tested was marked as an upright ball, and was so tested.

From a reference to Mr. Macbeth's remarks concerning absorption, regarding the test made by the Massachusetts Institute of Technology, one would be lead to believe that the company manufacturing the glassware under discussion has gone backwards instead of forward, the inference being that the glassware now used is not as good as that formerly employed. Such supposition is hardly worthy of discussion. As a matter of fact the manufacture has been improved.

Now as regards effect of dust—Mr. Macbeth wants me to lay particular stress on the fact that in the test under discussion we are dealing with an enclosing ball. I have already tried, to the best of my ability, in the paper, to convey such impression.

With reference to Mr. Godinez's remarks relative to the use of prisms on glassware, I must say that the company responsible for this development wants it thoroughly understood that such glassware as here shown is not marketed as being equal in physical efficiency, to that of its high efficiency reflectors. As stated in the paper, a certain percentage of this physical efficiency has been sacrificed in order to obtain effects associated with the artistic. The amount of loss is largely dependent upon formation and treatment.

Mr. Godinez would also like to know what per cent. of light in the lower hemisphere is obtained by skin reflection from the inner side of the reflector, and that obtained through the use of prisms. I would refer Mr. Godinez to figures 69 and 70. Figure 69 was made with an intensive reflector with a standard stiletto prism on the outer surface, and with a clear inner surface. Fig. 70 shows a curve obtained from a clear glass shade, same size and shape, as the reflector from which curve in fig. 69 was obtained. In other words, there is a plain shade having no exterior prismatic formation, with a clear inner surface, of the same grade of glass as that used in reflector from which fig. 69 was obtained. It is obvious that the skin reflection plays a very small part in the redistribution of light in this glassware.

Mr. V. R. Lansingh:—In Mr. McCormack's contribution to the symposium this statement in regard to uniform illumination—"From both the viewpoint of the public and the lighting company, installations of that sort are most undesirable." I think that he does not express quite what he means when he says that uniform illumination is undesirable. He means I think, that the monotony of the installations rather than the uniformity of illumination is undesirable, because uniform illumination as an engineering problem, irrespective of how it is obtained, is desirable in stores and offices. For example, in dry goods stores, where things are moved around from place to place and from time to time, uniform illumination is essential; also, in large offices where desks are moved.

Mr. McCormack also states that specular reflection and glare are practically synonymous. If one should look up at the inside of reflectors suspended above his head he would observe specular reflection. Of course, with a high polished opal or prismatic reflector there is a large amount of glare; but as a matter of fact one very seldom looks up into a reflector. The old adage of looking at the illumination and not at the light applies in this case. However, I want to call attention to the fact that as regards light on the work on this paper, for example—whether it comes from diffuse reflection or specular reflection, it differs not. There is no more glare on this paper if the light is specularly or regularly reflected from the light source than if it were diff-

usely reflected. The two are the same and the only difference comes when one looks at the light itself. In the case of specular reflection the area of lighted surface is generally smaller than it is in the case of the other; and, consequently, there is more glare; but with the same illumination (the same foot-candle intensity) falling on the work, there is no difference, whatever.

On another page the author says that a flat reflector depolished gives less glare than a polished reflector. It is hardly necessary to comment on that for the reason that a flat reflector exposes the bare lamp, and the glare from a bare lamp is much greater than that from even a polished reflector of that type.

Mr. F. L. Godinez:—Mr. Lansingh, I believe, in referring to Mr. McCormack's paper spoke of uniform illumination as being desirable in installations of a type where merchandise or counters perhaps might be moved. Certainly the small percentage of installations of that character it is quite desirable to have the lighting system installed so that it will not have to be moved with the furniture. In general installations of the commercial type, particularly in the form of long narrow interiors, of which there are hundreds of examples, most notably those devoted to the display of men's furnishings—the common plan is to illuminate such interiors with a single row of lamps and reflectors. Hence during rush hours when people are standing in front of the counters on both sides, the counters are in shadow and the merchandise is not properly displayed. Obviously in such a case uniform illumination is not desirable even if actually attained by two rows of lamps and reflectors suspended directly over the counters. To make installations original and attractive, which is most essential, it is advisable in some cases to install portable lamps of artistic appearance on the counters at such intervals that any merchandise which the customer might examine would be illuminated in such manner as to bring out the true color and character of the merchandise exhibited. An auxiliary system should be utilized in the display cases, using straight filament lamps. This would serve excellently for advertising purposes when the store was closed, since the show cases would stand out by contrast. The idea of using artistic ceiling fixtures and shades, in addition, simply to preserve an effect of originality

and appearance is commendable. Uniformity in some cases is desirable, but on the other hand an installation affording some real advertising value by its difference and attractiveness is by far the most important consideration.

Mr. Lansingh in referring to Mr. McCormack's paper said glare and specular reflection are identical. Dr. Cobb has verified Mr. McCormack's statement, and Mr. Stickney has also spoken of the disagreeable effect from polished surfaces of papers due to reflectors giving specular reflection and not those giving diffuse reflection. It is very true that often from a very highly polished surfaces reflected images of glaring light sources which are most objectionable are obtained. Manufacturers, therefore, provide depolished prismatic reflectors for commercial interiors in order to afford diffusion and cut down glare.

Mr. A. J. Marshall:—Speaking of collodial suspension: If you will refer to Mr. Godinez's paper (figure 12) you will find a cut showing suspended particles. These particles are only visible with the aid of the most powerful microscope—ultramicroscope. The specks that Mr. Hibben refers to, I think, are imperfections, and instead of aiding in the efficient distribution of light flux, act as impediments, giving rise to loss of light. They are also objectionable as far as appearance is concerned.

Mr. Young has made several contradictory statements in his paper as regards performances of Alba glass. He speaks of it first as having good reflection, partially controllable reflection, partially diffuse reflection, efficient transmission, true-color transmission, diffuse transmission, cleanliness and permanency, excellent physiological effects aiding in conservation of vision, possible advantageous physical properties of ultra-violet absorption and of fluorescence, artistic effects capable of being produced in both design and color, ability to assume the color of the light source, general balance of diffusion, transmission and reflection of light. If Mr. Young has omitted anything I fail to notice it. In the first place a glass of the milk or opal variety is either a good reflector or a good diffuser. It cannot be both, perfectly. The glassware that Mr. Young describes is not best suited for use as reflectors. It is a far better transmitter, and in the form of enclosing envelopes gives good diffusion with fairly low loss in

absorption. The chief characteristic of this glassware is an abnormal thickness of clear glass, in which, widely distributed, are minute particles visible through the aid of the ultramicroscope, and larger imperfections visible to the naked eye. While it is in most cases impossible to state the exact loss of light due to the interfering particles, giving rise to good diffusion, yet these particles are not so condensed as to prevent the passage of light rays through multiple reflection. If you will study the structure of an ordinary piece of opal, some two or three times thinner than the Alba glass, it will be noted that the particles are much compressed, and offer concerted resistance to the light rays, giving rise to high absorption when such glassware is used in the form of totally enclosing media. In Alba glass interference to the passage of light rays is not great. Hence there is afforded good transmission with low absorption making such glassware desirable for use as enclosing envelopes. The second class of glassware redirects the light, and therefore is a good reflector, also a good diffuser, but with high absorption.

I don't quite comprehend what Mr. Young means when he refers to cleanliness of glassware. I have heard it stated that certain formations of opal reflectors are very skittish; they refuse to associate themselves with such obnoxious matter as dust and dirt. However, dust and dirt are rather forward and likely to thrust themselves where they are not wanted.

Mr. Young speaks of true color transmissions as a fifth quality, and in the ninth he mentions possible advantageous physical properties of ultra-violet absorption and of fluorescence. These statements are highly contradictory. In one he states the glassware has selective absorption, and the other gives true color transmissions. If it is selective in its absorption, then the color is changed. Mr. Young would have us believe that the absorption of Alba balls giving good diffusion is almost nil. We, however, should not confuse Alba balls that do diffuse the light and those that do not—or not to a finished degree.

Mr. Young states on another page "Naturally the most readily cleaned surface is the one which is perfectly smooth and with fewest possible ribs or crevices." I note that all Alba glassware is made with these crevices or ribs. There has been so much

said about the question of dirt, and chiefly on one side, that I would like to say a word in behalf of the other. Take a piece of glassware approaching this in color (indicating white sheet covering table) and throw dust or dirt on it, and you will immediately have a contrast. On the other hand, place dirt or dust on this article (indicating clear glass tumbler) and such foreign matter is not near so easily discerned. It is simply a matter of contrast. Dirt and dust on opal reflectors are more easily visible than dirt or dust on clear or satin finished glassware. As a matter of fact dust or dirt detracts from the appearance of any glassware.

Mr. F. L. Godinez:—Regarding the curve which is shown on page 902 depicting a balance obtained between the flux in the upper and lower hemispheres,—it would perhaps be interesting to know how these values were attained. It is a somewhat difficult proceeding. I would also like to ask if the curves represented are those of an independent authority of of some manufacturing concern. Finally, I wish to enquire on what grounds does Mr. Young assume that the flakes or blotches characteristic of Alba glass are typical of colloidal suspension.

Mr. V. R. Lansingh:—Mr. Young's paper:—He mentions on one page that some fluorescence does occur in the case of Alba glass. I would be very glad if he or any body else can inform me just what evidence there is on that point.

Alba balls are made in two ways, pressed and blown. The blown has, according to the figures given in this paper, a very low absorption, 13½ per cent.; in the case of the pressed Alba balls, however, the absorption due to the increased thickness of the glass is very much higher, approximating thirty-three per cent.

Mr. S. G. Hibben:—In reply to that question concerning the reflection and the color from the specks or particles in suspension in the glass, I would like to say that this is probably a question the answer to which is based upon whether you consider the visible or invisible specks, or merely a question of their size; that is, the same specks somewhat larger than in the normal condition of the glass may be visible but in a little better grade of glass and in smaller sizes of glassware would approach more nearly the condition of colloidal suspension. But I

think probably reference is made to some cases where the specks are really air-bubbles or the like, occurring especially in blown wares, and in that case the larger specks or bubbles are to be considered exceptions and not the rule. The fine flakes—the very minute particles—are the ones to which I originally referred and which we do not attempt to eliminate in the normal making. And the glass has now been improved to such an extent that these larger specks no longer appear and the effect of these finer flakes is to give color and also to aid in the reflection.

In the paper is a statement that fluorescence occurs in Alba glass. I have no figures on this fact, but I have some statements made in connection with tests of the Cooper-Hewitt Company from which they find that they have determined to their satisfaction that a blown Alba hemisphere used beneath the Cooper-Hewitt coiled tube is of a material aid in conjunction with their fluorescence reflectors which were spoken of yesterday. Also some tests were made at the Carnegie Technical Schools and they got far enough to convince the investigators that there was likelihood of some fluorescence. I can't attempt to say just how much because the fluorescent screen at that time was found to be a trifle faulty and for that reason I state that that has not been definitely determined.

Mr. A. J. Marshall:—Mr. Hibben, may I put a more direct question? Do you consider these visible specks as being imperfections in the glass?

Mr. S. G. Hibben:—No I wouldn't say that. If you examine a shade very closely in your hand you will be able to see a large number of very small fine flakes. Those are the colored flakes that are an aid in reflection.

Mr. A. J. Marshall:—Then, as I understand you, the visible specks are the ones that do the reflecting, and those are the ones that you speak of as being suspended in opal.

Mr. S. G. Hibben:—No I don't speak of them as being suspended in opal. The Alba glass is a colorless crystal body and in it are suspended a number of flakes of various sizes. I don't know but what some of the smaller sizes would be considered invisible unless under microscope. From that size they run to

larger flakes. I suppose some of the gentlemen have seen various shades where the flakes were probably a thirty-second of an inch in size.

Mr. A. J. Marshall:—Have you ever examined any of those flakes to learn what their structure is?

Mr. S. G. Hibben:—I wouldn't attempt to state their composition here because that is more or less a secret process.

Item No. 7 in Mr. Young's paper, "Cleanliness and Permanency."—Doubt was expressed that there was any variation in the struction of glass. I think that statement ought to be modified slightly to conform with what is known by the glass makers. In fact I think that in the paper on the manufacture of illuminating glass given previous to this one mention was made that all clear globes particularly those containing manganese were subject to discoloration. I would like to call that point to the notice of the gentleman who states that glass is unchangeable. I think that is a very large and apparent change and is liable to occur in other than crystal glasses.

There was some question about the authenticity of curves as shown, for instance figures 5 and 6, and so on. These are curves made by the Electrical Testing Laboratories and I think should be considered authentic.

In regard to the question of ribs in the glass referring for instance to the sphere in figure 10, these ribs are used entirely as an artistic requisite. There is no photometric effect expected to be obtained by such elaboration. I would state that the ideas of the ribs are in no way expected to be a copy of any former elaboration and make plain the idea that the ribs are not for reflection or anything except the purely artistic.

MODERN REQUIREMENTS OF REFLECTOR DESIGN.[1]

BY F. LAURENT GODINEZ.

While the manufacturers' efforts in perfecting high efficiency illuminants have imparted a wonderful stimulus to the art and science of illumination by making light low in cost, it is to be regretted that the manufacturers of illumination accessories in general have failed to realize the necessity of preventing illuminants from becoming cheap in appearance.

The eye is unconsciously attracted toward a source of light but if no agreeable impression is thereby conveyed to the observer, the value of the source as a relative symbol of expression is negligible. The lighting equipment of mercantile interiors and display windows which should be productive of real advertising value, must be arranged with some regard for originality and ensemble, in order to provide a striking and pleasing contrast to installations of the "ready made" type.

In assuming that certain predetermined methods of lighting an interior admit of universal application the manufacturer has taken too much for granted. Such procedure terminates in monotony of design, and monotony, familiarity, and contempt are all synonymous in this implied sense. It would appear that the development of high-efficiency illuminants, and the intricacies of modern central station requirements have been too rapid for the manufacturer of reflectors to cope with, since little if any serious effort has been expended in striving to relieve the tedium of reflector design.

That the situation has assumed a critical aspect from the public utility viewpoint cannot be denied. Obviously the legitimate profit from the sale of energy in luminous form is dependent upon expansion, or the more extensive use of lighting service, and while presumably illuminating companies cannot persuade the adoption of gas and electric light in homes where the oil lamp would be regarded as a luxury and the candle as a neces-

[1] A paper read at the fifth annual convention of the Illuminating Engineering Society, Chicago, September [illegible] 1911.

sity, yet, for that very reason, the multiplication of semi-prosperous homes becomes an issue of vital import in their business, and it is an issue which can be faced only by a constant endeavor to better the working and living conditions of their communities. Expansion is fundamentally dependent upon satisfaction, resulting from the efficiency of the service, but beyond the preliminary stage it may be attained only by presenting the subject of illumination to prospective consumers in a most attractive and varied form.

These considerations have the utmost significance with reference to reflector design, and it is not at all strange that the representatives of public utility corporations should find difficulty in interesting prospective consumers when the incentives they have to offer are lacking in every feature of contrast, effect, and appearance.

In considering the requirements of modern reflector design it is possible to separate the subject matter under two general headings; namely totally-enclosing envelopes, and semi-enclosing envelopes.

The first division, may include various types of totally-enclosing envelopes in the form of spheres or stalactites,—with or without exterior ornamentation, composed of ground, acid etched, prismatic, or opal glass. Since the distribution of light flux from these secondary radiating surfaces is due principally to transmission phenomena characteristic of the media involved, it becomes necessary to study the effect of reflection and transmission therein due to diffraction, diffusion, or irregular reflection.

Previous investigators have established as a matter of scientific record the variations in the distribution of light flux in a vertical plane referred to the accepted theory of surface conditions of secondary radiating surfaces. It is apparent that a distribution curve resulting from the redirection of light flux may be modified to some extent by specular or diffuse reflection from either a polished or depolished secondary radiating surface of opaque or translucent media. While it has been asserted that secondary radiating surfaces dependent upon the phenomena of diffuse reflection do not modify the distribution of light flux below the horizontal to the extent characteristic of

surfaces dependent upon specular reflection, the fact that glare and specular reflection are synonymous, has evidently been overlooked. Such conclusions have been arrived at by a purely superficial consideration of surface conditions typical of reflecting and transmitting media and without particular regard for the actual structural phenomena of the media.

In such investigations the ultra-microscope affords a means of rendering visible the most minute particles within the structure of glass. It has been shown by numerous examples that

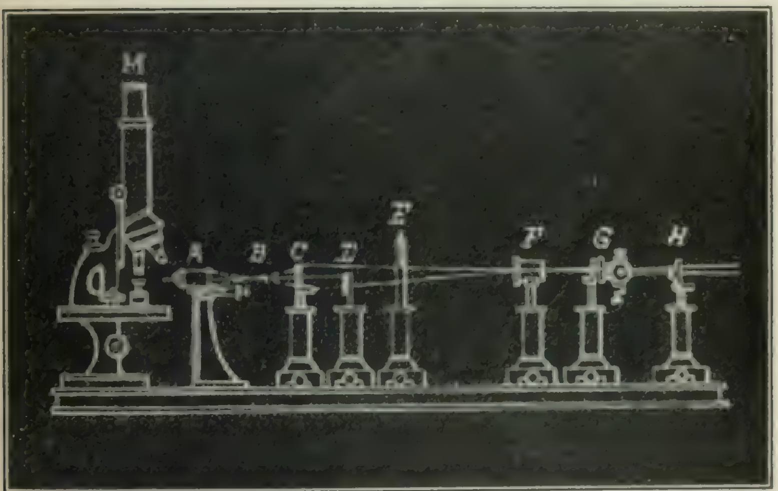

Fig. 1.—Diagram of ultra-microscope.[1]

the particles of a solid, such as metallic gold, change with progressive subdivision, especially if the subdivision be carried to a degree approaching molecular dimensions. Professor Richard Zsigmondy, instructor in inorganic chemistry at the University of Göttingen, has developed the subject of ultra-microscopy with reference to irreversible colloids, and, as a result of his research and experiments in the precipitation of colloidal gold, has been enabled not only to observe the size and color of the particles but also to view their motion.

In another research with reference to the microscopic nuclei

[1] "Microscopical Phenomena of Transmitting and Diffusing Media," F. Laurent Godinez and A. J. Marshall, *Illuminating Engineer*, vol. 5, p. [illegible]

in colorless ruby glass the gold particles, like those in colloidal solutions, were visible upon spontaneous crystallization. A description of the ultra-microscope employed by Dr. Zsigmondy and by the author is given below.

In previous microscopical observations individual particles in colloidal solutions or in ruby glass could not be seen, since with transmitted light the eye is dazzled and the divergency between the resultant differences of brilliancy in the objective field is directly due to the diffraction of light from very small particles. To render these particles visible it is necessary that they be intensely illuminated, and without any reflected flux entering the eye; moreover, the contrasting objective field should be as dark as possible.

Referring to fig. 1, solar rays reflected from a heliostat enter the darkened laboratory through an iris diaphragm, on an optical bench about 1.50 meters in length, equipped with a metal flange suppported on an adjustable stand, on which carefully adjusted pedestals hold the individual mechanism of the apparatus. The light rays first enter the telescope objective H at a focal length of about 19 mm. and a resultant image of the sun about 1 mm. in diameter is projected on a micrometer slit-head G (adjustable). By manipulating a horizontal bilateral slit the solar image may be reduced to 0.055 mm. The width of the slit is observable on the micrometer gauge attached to the drum connected with the regulating screw. The edges limiting the height of the slit are movable horizontally, admitting of a wide variation from 0.1 to 2.0 mm. apart. A polarizer F may be placed behind the slit in the optical train when desired. E is an iris diaphragm acting like a photometer screen and excluding any extraneous light which might be reflected by the edges of the slit. By manipulation of the chisel-shaped diaphragm D one half of the incident beam may be cut off, which is strictly necessary when immersion objectives are used in order to prevent distortion from the closeness of the objective. A second telescopic objective C of 80 mm. focal length forms a quarter-size image of the slit at the focal plane B by the Abbe condenser A. By means of the primary microscope objective used in the sense of a condenser the picture B (reduced to one-ninth its size) is projected into the subject for analysis. Full use is made of

the variable apparatus in the condenser system A by controlling and modifying the illumination of its posterior plane.

Two micrometer screws working in a horizontal plane and perpendicularly to each other enable the condenser objective to be readily centered in the optical axis of the microscope proper. In order to bring the desired portion of a solid within the axis of the incident beam Seidentopf has devised a metal prism with slides which permit the vertical micrometric motion of a minute plane, quite analogous to the familiar mechanical-stage of the ordinary bacteriological microscope.

In the examination of spontaneous crystallization in ruby glass Dr. Zsigmondy recalls the well-known analogy existing between the formation of ruby glass and the devitrification of amorphous substances. Differentiating between a microscopic, and sub-microscopic particles with reference to perfect or inferior ruby glass, he shows that the individual particles appear much brighter and further apart in the latter than in the former case.

The apparatus employed by the author in his present research work is an elaboration of the ultra-microscope described above, the addition being a microphotoscopic attachment, and the conclusions derived and hereinafter set forth represent the result of data obtained from the ultra-microscopic examination of ground, acid etched, opal, and milk glass.

The microphoto-gravures exhibiting the structural phenomena of ground and acid etched glass were obtained from observations made with a standard bacteriological microscope equipped with a Class A objective and a Huygens eye-piece Nos. 2 and 4. Use was made of an Abbe condenser with a special correction for chromatic aberration, and also of an iris diaphragm adjusted to the microphoto-camera direct.

Before proceeding to a consideration of the microphotographs showing the structural phenomena of ground and acid etched glass attention is directed to the accepted theory of diffraction and diffusion within such media as defined by Dr. C. P. Steinmetz.

In fig. 2. R represents a theoretical radiator within a totally enclosing envelope of ground or acid etched glass E. A pencil of light emitted from the radiator R, upon emergence in the direction I maintains its initial horizontal linear direction, but at a slightly reduced intensity due to absorption. Upon emer-

gence there is also a slight scattering of rays as indicated in fig. 3.

It should be noted that the dispersion is symmetrical with reference to the horizontal axis of the emerging ray. From

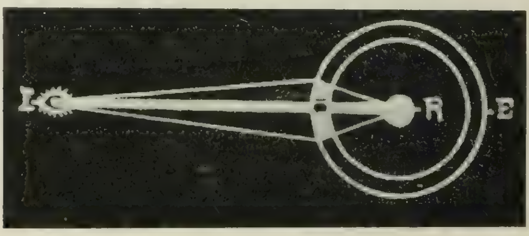

Fig. 2.—Theory of light transmission with ground glass.

this it is evident that the enclosing envelope appears to the eye as indicated in fig. 4.

The radiator assumes the appearance of an enlarged glaring blotch of light within a practically non-luminous and indefinite outline. This explains why ground or acid-etched glass is inappropriate in any form where a uniformly luminous surface

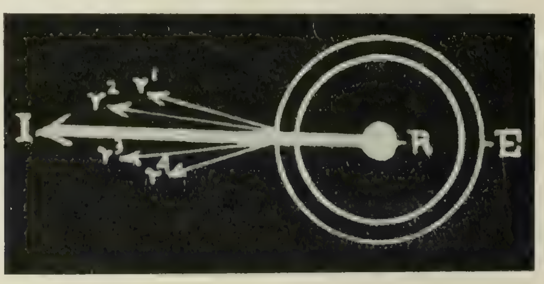

Fig. 3.—Dispersion of emergent rays with ground glass.

is desirable, unless an illuminant of low intrinsic brilliancy is placed within a sphere of large size, thereby increasing the distance from the surface to the source.

Fig. 5 is a microphoto-gravure of a ground-glass (CRI) plate, and by studying it carefully it is apparent why the pencil of light from the radiator R emerges as indicated in fig. 3. Naturally light acid etching produces an aggravation of the spot-

light effect on the secondary radiating surface, and this is also clearly shown by the microphoto-gravures in fig. 6 and 7, the former representing fairly dense acid etching, and the latter

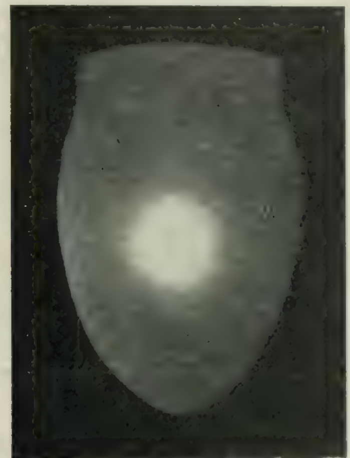

Fig. 4.—Photograph showing transmission effect with ground glass

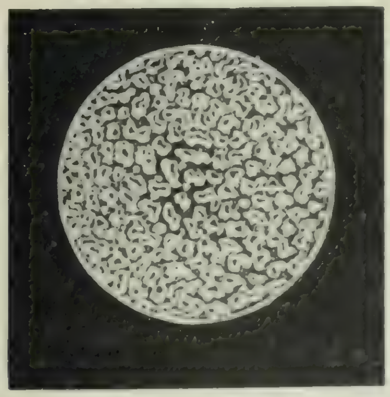

Fig. 5.—Ultra-microphotograph of ground glass

a very slightly depolished surface. The latter photograph was obtained only with repeated effort and great difficulty, since in order to reproduce the observed surface effect it was necessary to expose the plate to a dark objective field in order to admit sufficient light through the lens for adequate details without halation.

The only difference in appearance between ground and prismatic glass is that the irregular spot light effect in the former case is broken up into myriads of regular bright points in the latter,

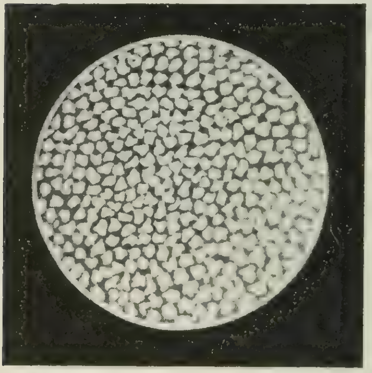

Fig. 6.—Ultra-microphotograph of dense acid etched glass.

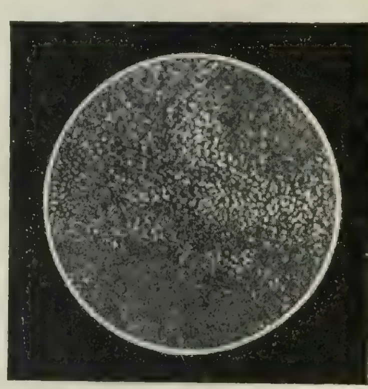

Fig. 7.—Ultra-microphotograph of light acid etched glass.

accompanied of course by redirection of the light due to the action of the horizontal external prisms.

In fig. 8 the radiator R is enclosed within an envelope of milk or opal glass, and upon emergence, while the horizontal linear direction is maintained, the intensity is greatly

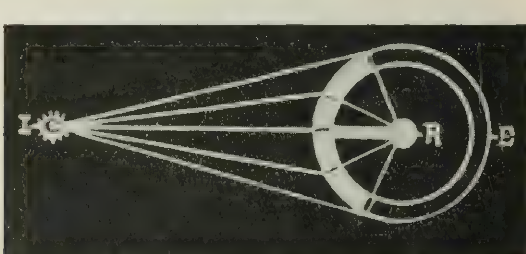

Fig. 8.—Theory of light transmission with opal glass.

diminished in the direction I. Consequently the surface of the envelope appears uniformly luminous, with the exception of a very minute central spot or line of light which is invisible at a short distance as in fig. 9.

When the envelope is of thin opal glass, and the radiator is an incandescent lamp of the carbon-filament type, the filament is visible at close range, exhibiting a characteristic red color, due to the translucent phenomena of opal glass for red waves.

Fig 10 shows the redirection of light flux by the action of sus-

Fig 9.—Photograph showing transmission effect with opal glass

pended particles of opal in opal glass. Dr. C. P. Steinmetz states that a pencil of light emitted from the radiator R upon emergence is redistributed with a maximum value at right angles to

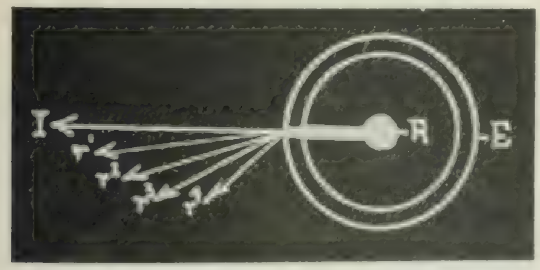

Fig 10. Redirection of light by suspended particles of opal in opal glass

any tangent drawn at the point of emergence. From this it is evident that with an enclosing envelope of opal glass the redistribution of light flux from the secondary radiator will be

symmetrical with reference to the form of the enclosing envelope.

With reference to fig. 11, Dr. Steinmetz[2] states: "The distribution of light flux thus depends on the shape of the diffracting envelope; that is a diffracting envelope leaves the distribution curve of the radiator essentially unchanged, and merely smooths it out by averaging the light flux over a narrow range of angles while a diffusing envelope entirely changes the distribution curve by substituting the diffusing globe as a secondary radiator and leaves only a small part of the light that of the direct emergent beam—the intensity distribution of the primary radiation unchanged. Thus, for a straight vertical envelope

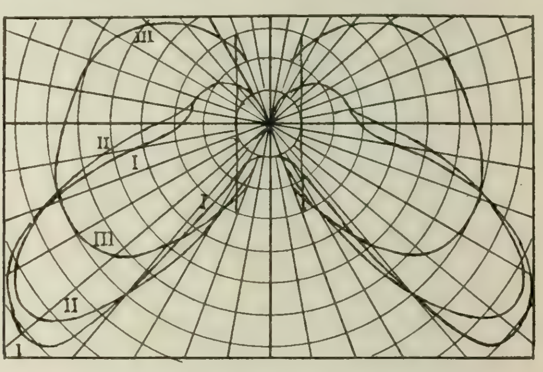

Fig. 11.—Distribution curves showing result of diffusing and diffracting envelopes.

surrounding a radiator giving the distribution curve shown in fig. 11, curve I, the distribution curve is changed by diffraction (frosted envelope) to that shown in fig. 11 curve II, but changed to that shown by fig. 11, curve III, by diffusion (opal envelope). The latter consists of a curve due to the transmitted light and of the same shape as I, and a curve due to the diffused light, or light coming from the envelope as a secondary radiator. The latter is the distribution curve of a vertical cylindrical radiator."

Fig. 12 is a microphoto-gravure showing the suspended particles of opal by the aid of the ultra-microscope. The photographic attachment employed by the author in this investigation was crude, and as a result this illustration, while quite

[2] "Radiation, Light and Illumination," Dr. C. P. Steinmetz, p. 223.

characteristic, does not do justice to the appearance of the object when observed through the ultra-microscope with the eye. These collodial particles of opal are generally oblateral in form, and are disposed between the structure of the glass with the majority of their major axes perpendicular to the plane of its exterior surfaces, which accounts for the redirection theory of light flux as mathematically proven by Dr. Steinmetz. The reason therefore for the visibility of a filament within an enclosing envelope of light opal glass is the unhomogeneous suspension of the opal particles which admits of considerable transmis-

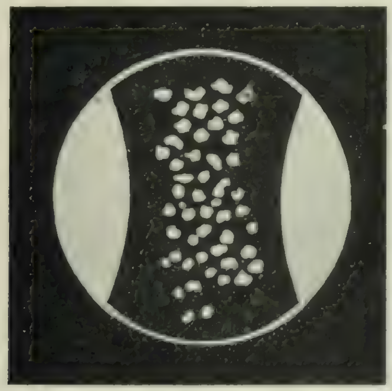

Fig. 12.—Ultra-micro photogravure showing suspended particles of opal in opal glass.

sion between them from impinging rays normal to the inner surface of the enclosing envelope.

This phenomenon is of special interest at the present day in view of the increasing intrinsic brilliancy of illuminants, and the fact that the Society for the Conservation of Vision is taking active steps to protect the eyesight of a suffering public. It would appear that further increments of intrinsic brilliancy will involve the placement of illuminants within entirely enclosing envelopes of such media as will decrease glare effect, and at the same time lend their exterior surfaces readily to the decorative treatment prescribed by the architect. The absorption loss through transmission is inconsequential when referred to the relative and augmented efficiency of modern illuminants. The use of

opal glass in the molded form of appropriate and beautiful historic ornament is peculiarly adapted to the environment of the home, and it is there of all places where the slightest regard for architectural consideration must prohibit the use of media suggestive in the least degree of the glassware typical of the commercial installation.

Frequently one is conscious of a sense of disquietude or unrest upon entering a room, which may be due either to offensive color analogies in decorative treatment, or to the color value of the illuminants themselves. Since the advent of the tungsten lamp the predominance of what has been termed "white light" effect has been quite marked amongst installations of the commercial type. This quality of light has been condemned by persons qualified to pass opinions on matters concerning art, on the ground that its effect is harsh and leaves a suggestion of tenseness to the features and an entire absence of harmony, expression, and ensemble.

Moreover the element of repose which is the basis of periodic design in the home, is conspicuous by its absence, and one need but revert to nature's teachings to realize why that element should invariably be present. Recall the beautiful and mellow influence of the setting sun on the animal kingdom, and remember that it was this sight which inspired some of the greatest masterpieces of art. It is this same natural and psychological precedent which has endeared to humanity the soft mellow light of the oil lamp, giving to an interior a touch of nature and an ensemble rich in tone, feeling, and expression. It has frequently occurred to the author that glassware embodying a proper relation between transmission phenomena and selective absorption would materially assist in supplying a long felt want, attainable with modern illumination at a consumption of 1.5 watts per candle, instead of 4.0 watts with the same quantity of light.

Dr. Herbert E. Ives, in response to a recent discussion in one of the technical societies, has shown that by tinting the bulb of a tungsten lamp a slightly yellow or amber color, only the blue region of the spectrum, containing the least total brightness is sacrificed by selective absorption. From Dr. Ives monograph on the subject the curve shown in fig. 13 represents the radiated

watts of a normally operated carbon lamp, while the small included curves are drawn to represent the luminosity values of the visible portions. Their areas are thus proportional to candlepower while the large curves are proportional to watts.

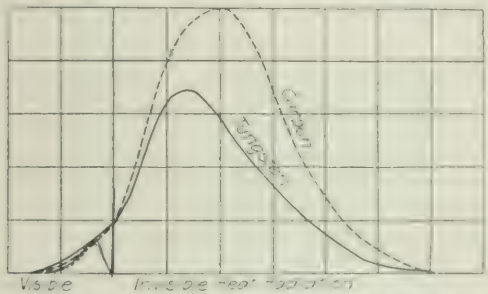

Fig. 13.—Radiated watts of normally operated carbon lamps

The spectrophotometric values for the relative brightness of the tungsten and carbon lamps, color for color throughout the spectrum, shows the necessary absorption to reduce the former to the color of the latter. These are shown in fig. 14, plotted in such

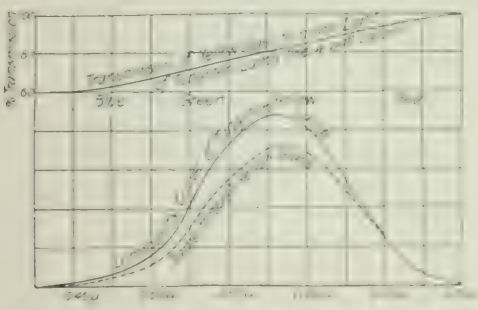

Fig. 14.—Spectrophotometric values for relative brightness of tungsten and carbon lamps

a manner that no absorption is called for at the edge of the visible spectrum in the red 0.70 μ, the absorption gradually increasing toward the blue. In the same figure the absorption values are applied to the brightness of the luminosity curve of the tungsten lamp. It is of interest to note that by tinting a bulb a delicate old rose the absorption is also relatively insignificant.

Unfortunately the treatment of the source in this manner is susceptible to considerable variation in uniformity of the manufactured product, and moreover there can be no assurance that the enclosing media in which the illuminant might eventually be placed would be appropriate in structure or artistic value. The logical procedure is undoubtedly to evolve independent media entirely adequate with reference to the working restrictions, and thereby relieve the illuminant manufacturer from a detail of manufacture which clearly should be referred to the producer of illuminating glassware.

To revert to the old rose tint, it may be barely necessary to mention the proclivity of the fair sex for radiation of a quality which serves in a measure to enhance the natural beauty of a complexion, and while it is indeed a colossal feat to hold the mirror up to nature, with a steady hand, the cause feminine is certainly worthy of Quixotic achievement.

As a result of considerable research along these lines the author has developed a new glass that is manufactured in a delicate amber tint just off the white, and also in a most subtle tone of old rose. The basis of the structure is opal and the depth of color and density is accomplished by the glass blower dipping his pipe first into opal glass, and then successively treating the material by processes which assist cumulatively in securing the perfect diffusion which is essential. An iridescent effect is attained by a special treatment of the surface with volatile chemical agents in the form of various chloride and hydrofluoric acid compounds, the corrosive action of the fumes of these chemicals giving a beautiful and permanent iridescence. The glass is also prepared without this effect.

While it is practically impossible to reproduce on paper the delicate *amber* and *rose* tints of this glass, a general idea of its appearance as a complete symbol of art in the Louis XVI period may be gathered from the illustration in fig. 15. This symbol aside from its pleasing conformity with periodic ornament, when illuminated is free from abrupt contrasts in color values. The same fixture with white glass would not only be inharmonious owing to the predominance of white, but would also lend a disagreeable harshness to the gold of the fixture which requires a

light rich in amber tones to accentuate properly its mellow luster. This criticism is quite general in its application.

The art lamp of the Colonial period shown in fig. 16 is an architectural conception of this new glass in old rose. It has been determined by research that there exists a critical value of color density in red which is flattering to the features of young and

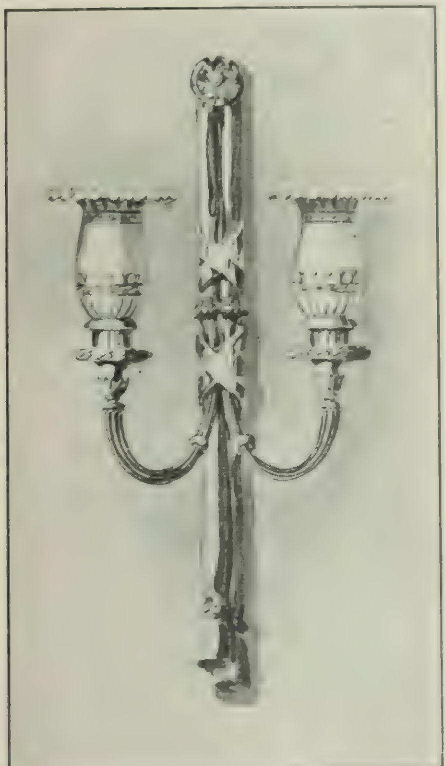

Fig. 15.—Art glass in Louis XVI period

old alike. With reference to transmission and selective absorption this critical value becomes virtually a saturation-point absorption factor dependent upon the uniform density of the medium and its homogeneity of coloration. Uniformity is attained by comparison with a standardized medium, and the rejections are approximately twenty per cent of the total.

Having concluded with that division of the subject appertaining to diffracting and diffusing media in the form of totally enclosing envelopes, a consideration of the second classification is next in order. Under this heading may be included semi-enclosing envelopes, acting as secondary radiating surfaces in redistributing light flux by diffuse or specular reflection.

In manufacturing circles the ethics of terminology with reference to the appellation "shade" or "reflector" has resulted in prolonged and heated discussion. Presumably a reflector acting in the implied sense of redirecting light must necessarily be a shade in the functional sense of shading the eye from transmitted light, otherwise one must accept the definition "reflector" to

Fig. 16.—Art lamp in old rose glass Colonial period.

apply exclusively to a device entirely lacking in occular comfort, and continue to expend valuable energy in hair splitting argumentation. However, it is quite certain that the intrinsic brilliancy of modern illuminants demands special recognition on the part of those engaged in the manufacture of improved illuminating appliances.

In any analysis of reflecting and diffusing media one is confronted with the fact that specular or regular reflection is invariably identified with surfaces which are polished, whereas diffuse or irregular reflection is characteristic of depolished surfaces. In other words, when a ray of light strikes a polished surface it is more or less sharply reflected depending on the angle of incidence, whereas if the surface is depolished the ray

is diffused or scattered so that no intense reflected rays enter the eye. The blurred print of the glazed reading page, the indistinctness of the illuminated and polished sign-board, and the distortion of oil paintings under direct radiation, are constant reminders that their is such a thing as specular reflection and glare.

In the design of reflecting glassware these principles apply with equal force. It is possible, therefore, to separate reflectors into two classes, namely, those acting by specular, and those acting by diffuse reflection. In the first class may be included prismatic glass and any reflector with an inner polished surface, of whatsoever material. In the second class may be included prismatic glass with a treated inner surface, opal or any other material interiorly depolished.

In the design of street lighting reflectors the manufacturers of prismatic glass have recognized the undesirability of glare from specular reflection and have endeavored to realize a distribution curve of zero glare effect on the assumption that the source of glare lies within the polar angles above 60 deg. and that its elimination requires the partial or entire suppression of flux within those angles.[3]

This theory has formed the basis of discussion before this society[4] and it has been asserted that pupillary contraction should be regarded as a purely protective function and not in any sense through its operation a cause of decreasing visual efficiency. This, however, is still a matter of opinion rather than fact.

In order to accentuate the importance of reconciling theory with actual practise in reflector design, whenever public utility corporations are directly concerned, one need only revert to the subject of street illumination from a viewpoint which has as yet never received the slightest intelligent consideration from the manufacturer, and that is the viewpoint of the public utility itself. These vast interests do not attempt to dictate to the reflector manufacturer but they are nevertheless thoroughly aware of their own exact requirements in all uses of artificial light. The attractive lighting of the display windows of their con-

[3] "An Analysis of Illumination Requirements in Street Lighting," A. J. Sweet, [illegible] *Franklin Institute*, May, [illegible].

[4] Preston S. Millar, "An Unrecognized Aspect of Street Illumination," [illegible] vol. 5, p. [illegible].

"Some Neglected Considerations Pertaining to Street Illumination," [illegible]

sumers is one of the vital features of their business. Its successful accomplishment leaves the visible trade-mark of progress on a community, and to the merchant there can be no more remunerative advertising medium. Obviously, therefore any innovation tending to mitigate the mutual benefits derived therefrom is to be condemned, particularly a system which directs so much light against a display window that the resultant glare effectually obscures the entire display of merchandise within, and eliminates thereby all advertising value. Reflectors for use in front of show windows should be designed to give an asymmetrical distribution calculated not to ruin the effectiveness of display window advertising, but to direct the maximum flux in the street, not on the sidewalk. In strictly business thoroughfares, street lighting should be treated more as a decorative function since even after the closing hour of shops in localities where midnight flat-rate schedules do not prevail, the intensity of illumination from a decorative system consisting of ornamental columns equipped wth adequate diffusing media is sufficiently high for all intents and purposes.

Unfortunately in interior lighting it is impossible to confine glare effect from specular reflection within certain angles, since the position of the eye becomes a variable factor not limited by the restricting linear direction of a sidewalk referred to a source as in street lighting. In offices, it is impossible to prevent the workers eye from straying frequently toward the source of light particularly if it is of a glaring nature and illuminates the clock dial.

On looking at an exposed filament of even a lamp of the carbon type for a few moments after-images result, showing clearly a disturbance of the balance of the retina. When this is aggravated by a multiplicity of filament images reflected within the surface of a reflector acting by specular reflection and with the tremendous increase in intrinsic brilliancy of the tungsten over the carbon filament, the result is decidedly irritating to the eye. In the case of prismatic reflectors it is only when they are so far away that the eye is unable to distinguish their individual surfaces, and the media of the eye can themselves perform the

necessary diffusion that there is any reduction in intrinsic brilliancy significant for the protection of the eye.[6]

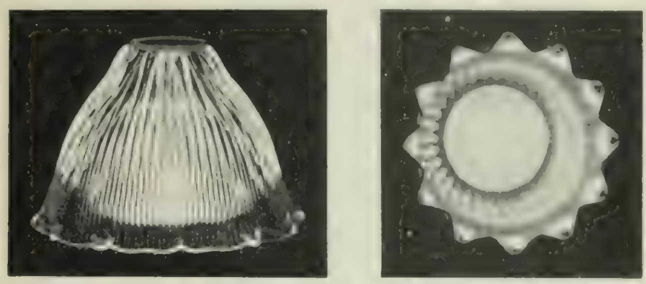

Fig. 17.—Photograph of a clear prismatic reflector and 100 watt bowl frosted drawn wire tungsten lamp.

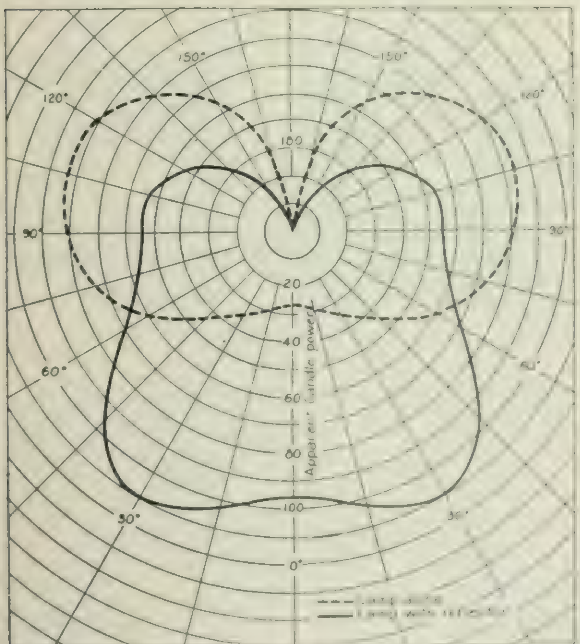

Fig. 18.—Distribution lamp flux of reflector shown in fig. 17.

Fig. 17 represents a photograph of a clear prismatic reflector of the intensive type over a 100-watt bowl-frosted drawn wire

[6] Percy W. Cobb, "Physiological Points Bearing on Glare," Trans. I. E. S., vol. 6, p. 157.

tungsten lamp. A mirror was placed beneath the unit at an angle of 45 deg. with the plane of the supporting base. The camera lens was directed at a point slightly above the lamp tip. The duration of the exposure was twenty seconds. A back felt curtain formed the background, accounting for the dark effect at the rim. The photographs of figs. 19 and 21 were made under exactly similar conditions.

The high lines of intrinsic brilliancy due to prismatic action and specular reflection are much in evidence. It is unnecessary to comment at length upon the correlation existing between the plate of the camera and the retina of the eye, except that in this case the camera is more fortunate in having a non-halation plate. The picture portrays in a way what the eye would feel in observation.

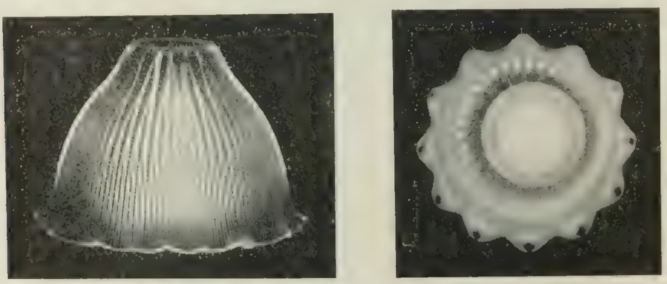

Fig. 19.—Photograph of prismatic reflector with "satin finish" and 100-watt bowl frosted drawn wire tungsten lamp.

In fig. 18 is shown the mean vertical distribution of light flux about the reflector shown in fig. 17.

Fig. 19 shows a photograph of a prismatic reflector of the intensive type with what the manufacturers term satin finish. It is apparent that the high lines of intrinsic brilliancy due to prismatic and specular reflection while subdued are still in evidence, but on the other hand the transmission of light is accompanied by less glare and more pleasing appearance.

The mean vertical distribution of candle-power about the satin finish intensive prismatic reflector of fig. 19 is shown in fig. 20. The modification in distribution due to the partially depolished inner surface is characteristic.

Fig. 21 is a photograph of a well-known opal reflector with a specially depolished and treated inner surface, showing

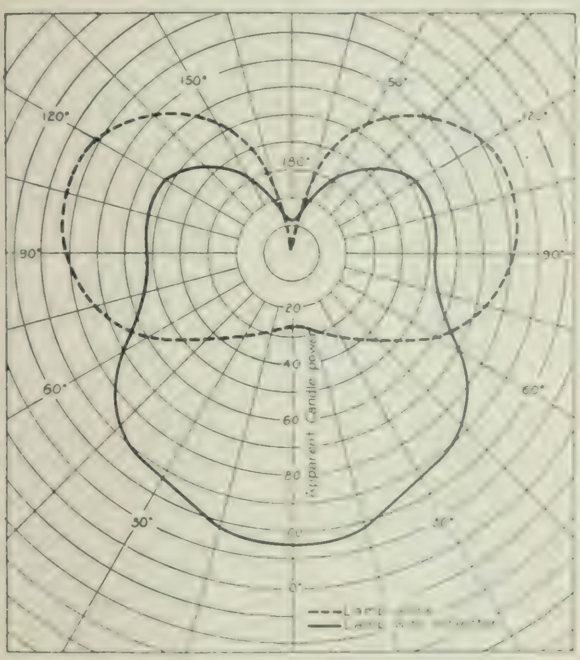

Fig. 20.—Distribution curve of reflector shown in Fig. 19.

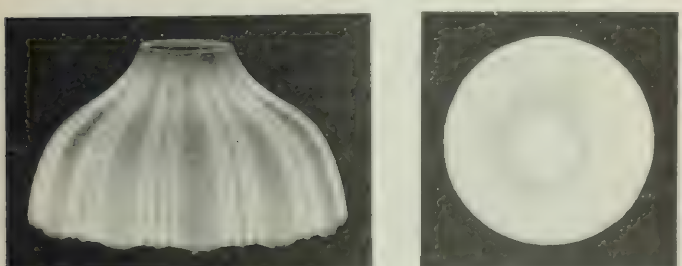

Fig. 21.—Photograph of opal deflector with specially depolished inner surface and 100-watt, bowl frosted, drawn wire tungsten lamp.

the perfect diffusion and pleasing appearance even when looking directly into the reflector.

The mean vertical distribution of light about the depolished and specially treated opal reflector of fig. 21 is shown in fig. 22 from which it is evident that in addition to perfect diffusion and absence of glare the utilization of flux below the horizontal is considerably higher than that shown in the preceding curves. The reflectors tested were selected at random, and by no means represent the best results selected from a number of special tests. From

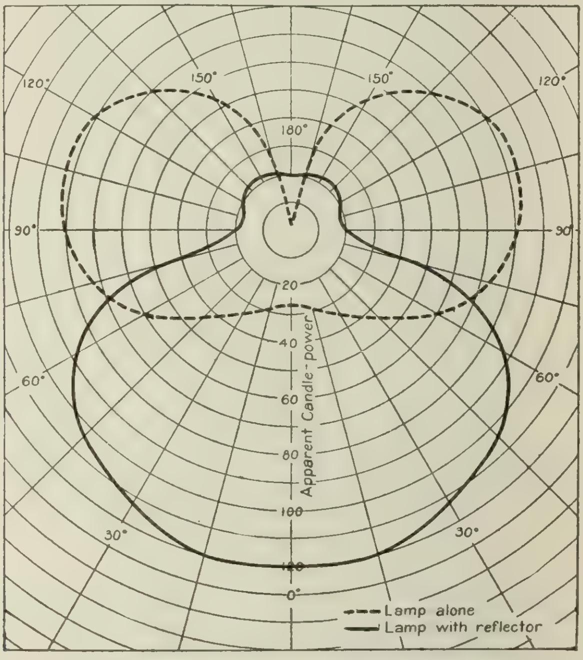

Fig. 22.—Distribution curve of reflector show fig. 21.

an inspection of these curves it appears that the upper hemispherical flux is greater in the first two cases than in the third. The question naturally arises as to the real value of the flux distributed to the working plane from this source. Unquestionably, light walls and ceilings have a less absorption factor than dark but here again is encountered a hitherto unrecognized factor which is again significant of the manufacturers' lack of appreciation for practical working conditions. The flux which is redirected to the plane by the reflection of ceiling and walls is

dependent upon two factors, and both are variables, namely, the quantity of flux transmitted through and above a reflector is depreciated by an accumulation of dirt, and the quantity of flux reflected from walls and ceilings is dependent upon the permanency of their color. Of course occupants of illuminated interiors are theoretically never presumed to change the interior decorations much less to allow dirt to accumulate on their lighting accessories, but they will persist in such irregularities: and while thousands of dollars are expended annually in cleaning windows to let natural light in, an insignificant figure would cover the amount spent in cleansing lamps and reflectors to let artificial light out. Moreover, in strictly commercial installations it is doubtful whether the high ceiling illumination of a mass of unornamental piping, wiring, fire nozzles and other equally ugly contraptions adds to the appearance of such an interior. From the viewpoint of the public utility corporation, again, it is the satisfaction of the consumer which must be obtained at any cost, and in order to do this it becomes necessary to eliminate all variables and uncertainties. The qualities which must be symbolical of the reflector manufacturers' product in this relation are reliability, efficiency and artistic appearance and above all the elimination of glare effect with due respect for conservation of vision.

In submitting formulas to the representatives of lighting companies for the rapid calculation of intensity of illumination, it is suggested that when a value in foot-candles is given as typical of any special condition attention should be directed to the fact that a factor of depreciation might prove a sensible adjunct, since the calculated values represent the initial performance of lamps and reflectors when new and clean, and are based on the unwarrantable assumption that lamps are invariably operated at the "top voltage", and that the decrease of candle-power with advanced life is a negligible factor. All these practical working considerations are worthy of detailed study, and in more ways than one does it lie within the scope and power of the Illuminating Engineering Society to come to the rescue.

While the work of the society has been distinctive and of the highest technical order, for that reason alone it has proven uninstructive to a large body of men who desire greatly to improve their conditions by acquiring information relative to il-

luminating engineering in a form which would be intelligible to a non-technical graduate.

The American Institute of Electrical Engineers and the American Society of Mechanical Engineers have published standardization tests of a most comprehensive nature. If the layman has reason to doubt the sincerity of the manufacturers' statement he can, and does, demand a test of the product in accordance with the standardized forms issued by these organizations.

The opportunities afforded by illuminating engineering to charlatanism, with the extreme youth of those posing as illuminating experts, has created a decided mercantile prejudice against anything even resembling the mercantile conception of an illuminating engineer. While no manufacturer of standing will allow misrepresentations to be made by members of his sales force, a precedent has been established of that sort by salesmen lacking broad training and a proper knowledge of their competitors' product. If the merchant could feel that there was in existence an impartial standardization test with which he might demand compliance by any manufacturer, an instantaneous respect for illuminating engineering and an appreciation for the society affording him such protection would ensue.

Imagine a situation wherein one salesman advocating the purchase of a diffusing ball giving a distribution of light flux covering a wide area, but with obviously no high intensity directly beneath the unit, conflicts with a competitor urging the adoption of a reflector which concentrates its light in a visible bright spot directly below the lamp and reflector and this in an installation where a fairly uniform intensity would prove desirable. The merchant may be won over to the latter's side by the absurd argument of the increased intensity or spot light effect beneath the source, no mention being made of an attractive scheme of lighting, appropriate color value, suitable fixtures or anything whatsoever to convince the purchaser that illuminating engineering signified aught but the attainment of various distributions of light, without rhyme or reason. This is but one of hundreds of examples which the author has personally observed during the past ten years throughout every section of

this country. It is mentioned in the hope that this society will take the initiative in placing before the representatives of public utility corporations standardization requirements which will prove of invaluable assistance to them in protecting the welfare of their consumers and in establishing, moreover, a universal respect for the Illuminating Engineering Society.

DISCUSSION.

Dr. P. W. Cobb:—The question of intrinsic brilliancy has come up again. I have just been quoted on this point and some remarks have just been made to the effect that specular reflection and glare are synonymous. I think it can also be said that refraction at polished glass surfaces and glare are synonymous in just the same sense. Mr. Lansingh has said with truth that as far as the illumination on working plane is concerned the difference between a diffusing reflector and prismatic reflector, giving the same distribution of illumination, is nothing. That is perfectly true, but it is scarcely ever that light sources are completely out of the range of vision, and for that reason the appearance of the lighting unit as a whole has to be considered. The point in regard to which I was quoted, and I think the point that Mr. Cady referred to a moment ago, was the question of the brightness of a refracted image. In a lens the intrinsic brightness of the image of an object seen against the face of the lens can be shown mathematically to be independent of its apparent size. It can be shown that if the image changes in size the light flux into the eye changes in exactly the same ratio, so that the reduction in intrinsic brilliancy of the image from the lens is merely a small fraction, which is constant, and which is the absorption of the glass itself. This holds equally for a prism with polished surfaces. I feel there is a good cause for congratulation on the fact that manufacturers of glassware are tending to bring out glassware with depolished surfaces and glassware made of a diffusing material for that reason.

Mr. Godinez has touched upon the question of the color of illuminants. I am hesitant about discussing the question of color as far as it relates to our physiological well-being. The element of repose which he speaks of in the case of the light of the setting

sun and the old kerosene lamp may possibly be due to other causes. Color of the setting sun does not approach that of the tungsten lamp until within ten or fifteen degrees of the horizon. We are only exposed to that color from the sun for a comparatively short part of the twenty-four hours. What the effect would be if that were continued for a much greater time is hard to say. Perhaps some explorer who has spent some weeks in the artic dawn or sunset would know more about that than we do. In both the cases of the setting sun and the kerosene lamp there is another factor which enters, and that is the question of shadows. The oblique or almost horizontal light of the sun low on the horizon casts very long shadows, and as a result of the dullness of the sky itself, very deep shadows, which I think are a factor in our pleasure in the landscape. The kerosene lamp as used in the home, gives, to be sure, a mellow colored light, but it also gives well defined shadows. I have a tungsten lamp installed at home in a table lamp so that the distribution resembles that of a shaded kerosene lamp and I do not find that the element of comfort and repose is absent. Moreover, in regard to the question of color I have been privileged to see almost daily a lighting unit in which the tungsten lights are so screened as to give light of daylight color. By a special screen the spectral distribution of daylight is almost mathematically matched. Very near this unit over my own desk happens to be a carbon lamp. When I first saw these two illuminants side by side I was struck by the apparent softness and pleasantness of the daylight color. The daylight device has a large surface which is more or less diffusing and which is the virtual source of light. The carbon lamp has a bare filament and an opaque reflector over it, so there is a wide difference in distribution, but the fact remains that others who have come in and casually seen the difference between the two lights seem to feel the same thing, namely, that there is a certain softness and agreeableness about the artificial daylight which is absent in light of the carbon lamp.

Mr. V. R. Lansingh:—On the third page of his paper Mr. Godinez states that glare and specular reflection are synonymous. I have commented on that before. They are only when you look into the reflector; otherwise, as I stated before, the illumination

falling on a given plane will cause no more glare in one case than in the other, whether reflection is specular or diffuse.

Mr. Godinez shows in his paper a photograph of the action of ground glass. It is interesting to note that in the case of ground glass there is probably a large amount of diffraction entering into the phenomena of dispersion. Refraction and reflection are common enough, but in the case of ground glass the edges of the particles are so sharp that there is undoubtedly a large amount of diffraction which ordinarily would not be considered as entering into lighting glassware.

Mr. Godinez states: "The only difference in appearance between the ground and prismatic glass is that the irregular spot light effect in the former case is broken up into myriads of regular bright points in the latter." That is true with the modification, however; in the case of prismatic glassware of this type the illumination over the entire surface is practically uniform, whereas in the case of ground glass there is a spot in the center and very little illumination from the rest of the globe.

Mr. Godinez has also said that in the case of houses it is undesirable to install any glassware typical of commercial installations. This is perfectly true probably in the case of high-class expensive houses, but in the case of nine out of ten glassware which is used in commercial installations can be used in more or less modified forms in house lighting.

Fig. 18 is a photometric curve of the intensive prismatic reflector shown in fig. 17. This probably is an extremely good illustration of the use of the wrong lamp or the wrong holder in testing a reflector of this type as the photometric curve is much distorted from what would be obtained were the correct lamp and the correct holder used. As a matter of fact, fig. 18 showing the photometric curve of a clear intensive type reflector, shows a less end-on candle-power than fig. 20 which illustrates the photometric curve of the same reflector satin-finished; whereas, when the reflectors are correctly used, the reverse is true. The correct curves are given below by the full line curves in figs. F and G. The dotted curves are reproduced from figs. 18 and 20.

The difference in distribution in the case of the clear reflector is so considerable that no further comment is necessary; in the

case of the satin-finish reflector it is not so appreciable on ac-

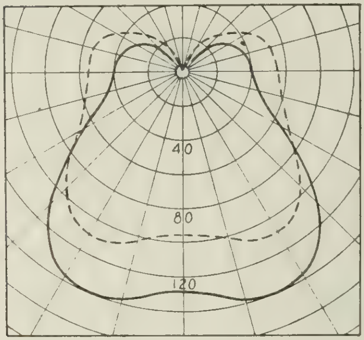

Fig. F.

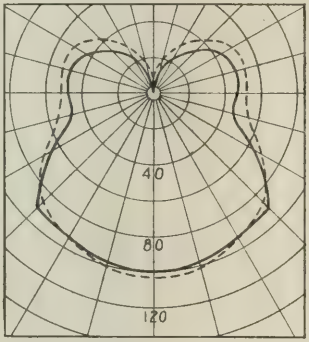

Fig. G.

count of the extent to which diffuse reflection enters into consideration.

The above illustrations indicate why conditions under which photometric curves are made should always be carefully studied.

Mr. Godinez has very sensibly called attention to the desirability of having a depreciation factor in figuring illumination due to dirt and depreciation of lamps. Most manufacturers, I wish to say, in all their rule of thumb methods have already taken this factor into account.

Mr. W. J. Cady:—In Mr. Godinez's paper is a comparison of the intensive reflectors, clear and satin finish. As Mr. Lansingh pointed out, it is evident that either the reflector and lamp were tested in other than the standard position or else a drawn wire lamp was used which was made by one of the lamp companies just after these lamps were first put out and before they were standardized for filament position and design. This is evident from the fact that the test on the satin finish reflector shows a greater candle-power at zero degrees than does the clear reflector and this would not be the case were the lamp filament in the correct position.

On the twentieth page of the paper Mr. Godinez shows a photograph of the inside of a satin finished reflector. I do not believe that any injurious effect would be felt from the reflection of the reflector itself, in looking into a satin finished reflector as

shown on that page. If any such effect were felt it would be from the direct light from the lamp itself.

It has been stated in the past that the intrinsic brilliancy of prismatic globes, speaking now of globes having horizontal refracting prisms on the outside and vertical diffusing prisms on the inside, is as great or nearly as great as the intrinsic brilliancy of the lamp itself, the argument being that the facets or prisms act as lenses. The inside prisms are so designed as to diffuse the light almost uniformly in a horizontal direction, while the outside prisms direct the light in a great number of directions in the lower hemisphere, with a predominence of light in one direction. Each facet therefore, acts as a diffusing particle, not with an intrinsic brilliancy as low as a perfectly diffusing particle, but possibly twice as great. The intrinsic brilliancy of the whole globe would be the apparent candle-power in the given direction divided by the effective projected area.

Messrs. P. S. Millar and W. F. Little (Communicated):—The accuracy of the photometric curve shown in figure 18 of Mr. Godinez's paper has been challenged by Messrs. Cady, Marshall and Lansingh. This curve was reported as a result of a test made by the Electrical Testing Laboratories. As stated in the paper, the unit tested consisted of 100-watt, bowl frosted, drawn wire tungsten lamp, and an "intensive" reflector purchased in the open market without any particular selection.

It has been stated that the filament location within the reflector is accountable for the difference between the curve as seen in figure 18 and that shown in Mr. Lansingh's discussion. The filament location as used in the former case was such as would obtain with a form H holder and a lamp whose dimension from the light center to the base cap is 5 1/16 inches. In the latter case we understand this dimension to be 4 15/16 inches.

The question of lamp dimensions is somewhat involved, because the official standard dimensions for the drawn wire tungsten filament lamps have not been promulgated. Efforts to secure such figures proved futile and at the time when the test was made (Aug. 21st) we were compelled to rely upon the correctness of the dimensions as furnished by one of the large lamp manu-

facturers to whom we were referred as a result of our efforts to secure the standard dimensions from the manufacturers' standardization committee. It is to be noted that since the test was made, advice has been received from the manufacturer mentioned above to the effect that this standard distance has been increased to 5 1/8 inches, which, it will be noted, differs still more from that employed in the tests which have been advanced to demonstrate the incorrectness of the curve shown in Mr. Godinez's paper.

In order to test the correctness of the curve shown, additional measurements have been made, using photometric apparatus of entirely different design, which showed a substantial verification,

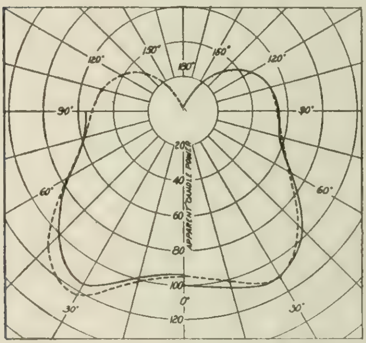

Fig. A.

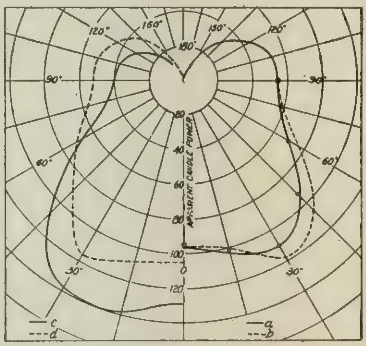

Fig. B.

also employing other lamps and another reflector. The results of these tests appear in the accompanying diagrams.

In diagram A, the curves on the left show tests of the same reflector with two lamps, both substantially correct as to dimensions, but differing slightly as to the bowl frosting. The tests on the right side of the diagram show a comparison between two reflectors used with the same lamp.

In diagram B, (right) appears (a) the curve included in Mr. Godinez's paper with indications of repeated measurements under similar conditions, (b) the mean of a number of curves obtained with new lamps in which the standard dimension is 5 1/8 inches between base and cap and center of filament, and (c) (left) the curve advanced by Messrs. Cady, Marshall and

Lansingh as typical of this lighting unit, (d) curves obtained at the Electrical Testing Laboratories with the lamp filament in the same relative position.

The conclusion which we reach is that taking into account the variables which may enter into the distribution of light about such a unit, there is no reason to expect more than slight variations from the curve shown in Mr. Godinez's paper, so long as the conditions are approximately standard. We fail to see how, under any conditions which are approximately standard, a curve similar to that adduced by Messrs. Cady, Marshall and Lansingh could be obtained.

Since the convention, we have sought to arrive at a curve to which these gentlemen and ourselves can subscribe, but through no fault of our own practically nothing has been accomplished in this direction at the time of going to press.

Mr. George H. Stickney:—One point brought out in the discussion this morning is at variance with my experience and observation. That is that a glaring source affects the eye only through light transmitted directly from the source to the eye, and not through the light received from the objects illuminated. This would, of course, be true if all illuminated surfaces were purely diffusing. Desks, counters, and often the paper of books and letters give more or less direct reflection. In a large room with a number of lamps it is often difficult to avoid these more or less distinct reflected images of the light sources. And the more glaring the sources, the more conspicuous and annoying are the images. Owing to the direction whence it comes, glare reflected from desks, counters, etc., may be more objectionable than that received directly from the light source.

Mr. F. L. Godinez (In reply):—Referring to the sixth page of my paper, it has been asserted that the filament of the lamp was tested in the wrong position, owing to the distortion of the well known "intensive" curve. At this point two questions may be answered simultaneously.

Referring to the curve of figs. 18 and 20, Messrs. Cady and Lansingh both alluded to the peculiar distribution and distortion obtained by a prismatic reflector of the intensive type. I have never been able to discover any published photometric curves of

prismatic reflection, either of the extensive or intensive type, since the advent of the new drawn wire tungsten lamp. So it became necessary to secure one of these latest lamps standardized by the Electrical Testing Laboratories and tested with an intensive prismatic reflector. It has been shown conclusively in a preceding paper by Mr. Marshall that the slightest variation in filament position modifies the distribution curve. Of course, it is immaterial whether this modification is accomplished by a change of holder or by a change of filament position in the lamp; the result is equally unsatisfactory. As it happens the new drawn wire lamp filament is in a considerably lower position than the old type lamp from which the extensive and intensive curves of prismatic reflectors were obtained. It is evident from the above that the very "flexibility" of prismatic glass is its greatest weakness, since with every illuminant improvement involving a change in filament position, the distribution curve attained by prismatic, or specular reflection is modified and distorted. From the appearance of fig. 22, it is apparent that with an opal reflector with a depolished inner surface and the same lamp and filament position used in the case of the prismatic reflectors that the distribution curve is free from distortion and much more satisfactory. All these curves were made by the Electrical Testing Laboratories with their usual care, discretion and reliability.

Mr. Lansingh in referring to ground glass globes spoke of the fact that the prismatic globe was of course uniformly illuminated even if the prismatic action did result in the breaking up of the light into a series of regular bright points. That is quite true, but in the case of ground glass there is one bright spot of light in the center and in the prismatic globe myriads of bright spots covering the entire surface; so the area of intrinsic brilliancy and annoyance to the eye is much greater in the latter case.

Referring to installations of commercial glassware in the home, I can conceive how Mr. Lansingh might infer in some cases that people of no discernment would introduce glassware in the home of the type which had been identified with cheap commercial installations; but it is difficult to believe that persons of refinement could defile the environment of the home by intro-

ducing reflectors of a type identified with or suggestive of the crude commercial interior.

Regarding the effect of looking into a satin finished reflector, a prismatic or a polished type as shown photographically in figs. 17, 19 and 21 of my paper—it is understood that lamps and reflectors are not hung in such a position that the lamp tip is staring one in the face, but as Dr. Cobb has emphasized it is practically impossible for the eye to refrain from straying to a source of light, and of course with specular or prismatic reflection, sharp, disagreeable rays of light must enter the eye.

Dr. Cobb refers to the question of color, alluding, I believe, to the new glassware which was mentioned in my paper. I quite agree with Dr. Cobb in his observation that "color is more or less of a habit." But for some psychological reason people have actually become attached to the color effect of the oil lamp. Whether the heat has anything to do with it or not is immaterial and irrelevant, but it is certain that the mellow effect and tone is universally pleasing. I feel that this question must be, for some time to come, simply a matter of public opinion. Many will agree that they desire such an effect in the home while others will prefer an absence of shadow as more agreeable. Here again is encountered the desirability of contrast in one's intimate surroundings. If in a living room one sees the four walls with unfailing regularity throughout the day, with every detail of wall decoration, pictures, and bric-a-brac, obtruding this becomes monotonous. If at night a mystic veil of shadow descends enhancing the aspect of an agreeable light source on a center table suggestive of mellow warmth and pleasing harmony, and adding in the general or partial softening of the enclosing dimensions, the feeling inspired perhaps is really one of complete repose. In the accounts of the recent coronation in London are frequent allusions to the wonderful "mystery" of the ceiling of Westminster Abbey. The only reason that this ceiling was mysterious was because it was not brightly illuminated. If it had been, there would not have been any mystery.

With reference to the utilization of the flux above and below the horizontal from a reflector, it is true that in all the different

[1] P. S. Cobb, Physiological Point Bearing on Glare. TRANS. I. E. S., [illegible]

forms of opal glass manufactured there is considerable variation. However, with a very dense opal interiorially depolished (fig. 21), a slight amount of light flux will be transmitted above the horizontal (fig. 22) and consequently a slight amount will be returned to the working plane by the reflex color action of the walls or ceiling. This is significant for the reason that if one desires to maintain a certain fixed intensity of illumination throughout the life of an installation it perhaps would be better to install reflectors of a type whose reflection of the flux below the horizontal might be regarded as constant, and not dependent upon any transmitted upper hemispherical flux, which varies with the changing conditions of decorations and the effect of dirt falling on the exterior of a reflector and impeding its transmitted flux upward.

Mr. Cady's observation concerning the intrinsic brilliancy of prismatic reflector surface and the intrinsic brilliancy of filament source has been answered by Dr. Cobb's verification of Mr. McCormack's statement that "glare and prismatic reflection are synonymous." The subject need not entail prolonged discussion; the results as photographically indicated may be convincingly verified by simple ocular demonstration.

In selecting reflectors for installation requirements it must be decided whether the efficiency of the lamp and reflector or the efficiency of a system dependent upon variable conditions is desirable. In my paper the value of upper hemispherical-transmitted flux as a contribution to the working plane is mentioned. In order to determine the exact significance of the absorption factors of walls and ceilings in actual practise consider a yellow wall having an absorption factor of 60 per cent. The interior bounded by this wall, let it be assumed, is to be illuminated by a 10-inch ground glass ball enclosing a 150-watt, clear tungsten lamp. The lumens emitted in the various zones are as follows:

Angle		Lumens
0 - 60		216
0 - 90	Lower hemisphere	505
90 - 180	Upper hemisphere	501
0 - 180	Total flux	1,006

Hence 501 lumens are from the upper hemisphere. It is evident

that three reflections must take place before this light flux reaches the working plane. Hence,

501 less 60 per cent. (300.6) = 200.4 after 1st reflection
200.4 less 60 per cent. (120.24) = 80.16 after 2d reflection
80.16 less 60 per cent. (48.09) = 32.07 after 3d reflection

Now let it be assumed that the occupants of this interior have decided to redecorate the room with a lighter, blue paper, having unfortunately an absorption factor of 75 per cent. Without deducting for the depreciation in candle-power due to the lamp life, and assuming that the accumulated dirt on the outer reflector surface has no effect in retarding the transmission of upper hemispherical flux, with the same value of lumens in the upper hemisphere as previously, the following results would be obtained:

501 less 75 per cent. (375.75) = 125.25 after 1st reflection
125.25 less 75 per cent. (93.93) = 31.32 after 2d reflection
31.32 less 75 per cent. (23.49) = 7.83 after 3d reflection

Therefore in the first case, with the yellow wall paper, the net contribution to the plane would be 32.07 lumens or 3.1779 per cent. of the total flux, and 6.4 per cent. of the upper hemispherical flux. In the second case with the light blue paper the 7.83 effective lumens would represent 0.77 per cent. of the total flux, and but 1.56 per cent. of the upper hemispherical flux. Granting for the sake of argument that this infinitesimal quantity is of vast importance, one must admit that its value is strictly dependent on variable, external factors which are beyond the control of the manufacturer. It is appropriate, therefore, in choosing reflectors, for mercantile interiors in particular, to select those which utilize the greatest percentage of light flux below the horizontal, and are not dependent upon transmitted flux and its absolute dependence upon reflector surface cleanliness or the permanency of wall and ceiling tints, with perpetual decorative conditions.

As a matter of interest I might add here that within two months in fifty cities in this country a monthly statement will be mailed on every bill rendered by the lighting companies to their consumers stating that all installations designed by the illuminating engineering department or illuminating engineer

of the local company will be officially guaranteed to give satisfaction, and if not satisfactory in any way will be restored to such condition, or modified to suit the consumer. On the other hand, the lighting company will assume no responsibility whatsoever for any installation not designed by their engineering department. In addition to this, for all consumers who desire to change their lighting equipment or for new consumers who are considering a new equipment, attractive sketches will be prepared showing the new arrangement and enhanced appearance of the interior as it will look when complete with the fixtures and reflectors as designed by the illuminating engineering department. This will of course increase the respect of the public for genuine illuminating engineering, and at the same time will strengthen the position of public utility corporations by directing their consumers attention to the many physiological, psychological and esthetic phases of the subject which in their entirety constitute the art and science of illumination.

ANNUAL MEETING.

The annual meeting of the society will be held in New York on Friday evening, January 12, 1912. This will be the occasion of the inauguration of the new administration and the conduct of certain other business. A detailed announcement will be mailed shortly to each member.

TRANSACTIONS OF THE

Illuminating Engineering Society

VOL. VI. DECEMBER, 1911. NO. 9

COUNCIL NOTES.

A meeting of the council was held in the general office of the society, 29 West Thirty-Ninth Street, December 8. Those in attendance were A. E. Kennelly, president; H. E. Ives, A. S. McAllister, G. S. Barrows and P. S. Millar, general secretary.

A statement of the society's finances and membership was presented by the assistant secretary.

From the finance committee a report constituting the approval for payment of vouchers aggregating $885.57 was received. Payment of the vouchers was authorized by the council.

Dr. Ives, chairman of the committee on reciprocal relations with other societies, presented the following report:

At a meeting of the committee on reciprocal relations, held Thursday, December 7, the following plan of campaign was decided upon, subject to the approval of the council:

The chairman of the committee will shortly write a letter to the presidents or secretaries of the societies with which we wish to open relations. This letter will call attention to the dependence of illuminating engineering on the several arts and sciences, and to the wide range of trades and professions interested in proper lighting. Our realization of our own need for closer touch with the underlying sciences and with the ultimate users will be dwelt upon, and the suggestion made that mutual good result from an exchange of views. With the object of securing a better acquaintance with each other's work, the following specific suggestions will be made.

1. Our secretary's office will be prepared to furnish at any time a list of all papers which have been presented before the society upon any particular subject, or the complete index of papers in the transactions may be had. These will not only serve to acquaint the recipients with the work of this society but will assist them in choosing qualified speakers when illumination topics are considered in their own meetings.

2. The secretary's office has in preparation a list of members who are qualified to discuss various topics, and to those organs of our own

papers are to be sent. If other societies are so desirous the secretary will send titles or advance copies of their papers to the appropriate members of this list. Similarly, our society would be glad to supply advance copies of its papers to be circulated among selected members of the societies, with the invitation to take part in our discussion. By this means each society should insure discussion of all sides of a topic.

3. Others will be asked to invite an official representative of our society to serve on each committee dealing with purely illuminating engineering questions. Through this representative it is hoped, overlapping or duplication of work by different societies will be avoided. Such matters as standardization rules on lighting will not be adopted until approved by our society, and in time the Illuminating Engineering Society will be recognized as a clearing house for all legislation on illuminating problems.

It is intended that, if possible, this official representative of our society shall be as well a member of our committee on reciprocal relations. The membership of the committee will thus ultimately be made up largely of men who know what is being done in other societies, and are in a position to see that the Illumination Engineering Society is not overlooked.

The bodies with which communication will be opened are:
American Institute of Architects.
American Association for the Conservation of Vision,
American Gas Institute.
American Institute of Electrical Engineers,
American Ophthalmological Society,
National Commercial Gas Association,
National Electric Light Association,
Association of Railway Electrical Engineers,
American Society of Mechanical Engineers
Association of Edison Illuminating Companies,
Association of Iron and Steel Engineers,
American Medical Society,
Cotton Manufacturers Association.

The foregoing report was approved and endorsed by the council.

The following amendment to the by-laws was read a second time and adopted:

Omit the phrase "by a public auditor" in Article 4, section 7, which reads as follows:

"The accounts of the secretary and the treasurer shall be audited annually just prior to the annual meeting, by a public auditor."

The following proposal to amend the by-laws was read for the first time:

Article III, section 3. Change this paragraph to read. "When applications for admission are received from persons residing within the territory of a section the general secretary shall notify the secretary of that section and shall request the board of examiners of the section to make a prompt report upon the applications.

It was also proposed that a by-law be inserted in connection with Article VII, section 12, of the constitution to read as follows:

A revised report of any member's discussion on any paper must be received at the general office of the society within ten days after it has been mailed to the member, otherwise revision shall be made by the editing committee.

SECTION MEETINGS.

CHICAGO SECTION.

The Chicago section held its monthly meeting December 16 Mr. C. W. Bender of the National Electric Lamp Association, Cleveland, read a paper on the drawn-wire tungsten lamp.

A list of the papers that have been arranged for the future meetings of the Chicago section is as follows:

January 18, "Church and Auditorium Lighting" by Mr. A. J. Morgan of the National X-Ray Reflector Company of Chicago.

February 15, "Office Lighting" by Mr. S. E. Church of Sears, Roebuck and Co. of Chicago.

March 21, a paper on "Visual Acuity" by Mr. A. J. Sweet of the Holophane Company.

April 18, a paper on School Lighting. The name of the author has not yet been announced.

May 16, The Manufacture of Illuminating Glassware. The name of the author has not yet been announced.

PHILADELPHIA SECTION.

Dr. W. M. L. Coplin, director of the Jefferson Hospital, Philadelphia read a paper entitled, "Institutional Lighting with Special Reference to Hospitals" at a meeting of the Philadelphia section held December 15.

The following program for future meetings has been announced:

January 19, 1912, A paper entitled "Illumination of Interiors by Daylight and by Artificial Light" will be read by L. B. Marks. Mr. V. R. Lansingh will deliver a lecture entitled, "The Architect and Illuminating Engineering. It is also planned to precede the paper of the evening with a short talk on the rudiments of illuminating engineering by Prof. Arthur J. Rowland, director of the School of Engineering of Drexel Institute, Philadelphia. Similar talks by Prof. Rowland will be given at each of the succeeding meetings of the Philadelphia section this season.

On February 16, Prof. George Hoadley, professor of physics at Swarthmore College, will deliver a lecture on "The Physics of Light."

NEW YORK SECTION.

At the meeting of the New York section which was held December 14, Dr. Ellice M. Alger read a paper on "The Conservation of Vision." The paper appears in this issue.

The program of papers which has been announced for the future meetings of the present season is as follows:

The January meeting will be devoted to a general discussion of street lighting.

At the February meeting a paper on visual acuity will be read.

Two papers will be presented at the March meeting, one on the relation of light to art and photography and the other on the relation of photography to photometry.

At the April meeting a paper on mine lighting will be presented.

The names of the authors of the above-mentioned papers have not yet been announced.

NEW ENGLAND SECTION.

At the January meeting of the New England section, two papers will be presented, one by Messrs. C. H. Sharp and Preston S. Millar and the other by Dr. H. E. Ives.

THEATRE ILLUMINATION.[1]

BY F. A. VAUGHN AND G. H. COOK.

Illuminating engineers have contended that illuminating engineering as a profession must embrace and be coordinated with many of the fundamental principles of other branches of science and art than engineering, optics and illumination. The principal branches so co-related to illuminating engineering include physiology, psychology, ophthalmology, architecture, interior decoration, fixture design, and other liberal and fine arts and sciences. That contention is convincingly exemplified in the application of the principles of illuminating engineering to theatre illumination—the subject of this paper.

In theatre illumination laws of light, illumination, and psychology, should be so effected that the patron of the theatre will neither be aware of any disturbing influence from the lighting conditions, nor have his enjoyment—the purpose of his presence in the auditorium—impaired; so that it will not detract from the pleasure of social intercourse through the medium of little visits between the acts, or visually through the use of opera glasses upon the well dressed audience; so that the temperamental eccentricities and the artistic feeling of the actor artists will be catered to by pleasant, effective dressing-room lighting, and by realistic, non-disturbing stage lighting; so that the multifarious tastes of the laity from every station in life who frequent the performances will be appealed to in as average and uniform a manner as possible; so that the deception of the audience by illumination effects, into the happy state of not realizing the "sham of it all," is accomplished; so that the attention of the passerby will be attracted to the management's desire to receive their patronage; and so that the warm and inviting quality and quantity of the illumination of entrances and foyer will be effective. To say the least, the requirements of effective theatre illumination are numerous and varied.

Many of the principles of physiology and ophthalmology must be contemplated and applied in such manner as to avoid as much as possible the fatiguing discomfort arising from the great

[1] A paper read at the Chicago section of the Illuminating Engineering Society, November 16, 1911.

glare, due to light sources placed in the range of vision, and the resulting drowsiness, eye strain, and headache; and also to avoid the resultant depressions of vision caused by the necessity of viewing objects beyond these sources. Due consideration must also be given, in connection with the professions of architecture and interior decoration, to the bringing out of the beauties of the ceiling, proscenium, facade, foyer, hangings and costumes; the last forms a large part of the decorations of a well filled auditorium.

Here one point should be emphasized: Through the cooperation of the architect, the interior decorator and the illuminating engineer remarkable results in efficiencies and pyschological effects may be obtained, especially by an intelligent selection of tints and colors for reflecting surfaces and general decorations, together with a consideration of the tonic effects of red and the sedative effects of blue, and the deception as to actual quantity of light which accompanies high absorptive qualities in the decorations.

Then, too, harmony must exist between the ideas of the illuminating engineer and the fixture designer, so as to properly adapt them to the artistic and harmonious embellishment of the general interior effect. The colorings, tints and textures of all parts of the auditorium must also be considered, so as to take into account or counteract the absorptive powers and other disadvantageous or advantageous qualities.

Lastly, there is one other phase which has not been included in the foregoing paragraphs; it is more plebeian than any of those that have been mentioned; and it necessarily has the greatest influence on the results accomplished by the illumination scheme: it is financial economy. Too often a theatre manager is so exacting in his methods of economy that an illuminating engineer finds it extremely difficult to provide the best illumination scheme for the theatre.

Theatre illumination may be divided into many types, classes and divisions, varying widely in their principles, applications, scope and results. Fig. 1 shows a more or less complete classification of them.

In the exterior lighting of theatres two extremes may be observed: one is the use of sign, studded incandescent and flame

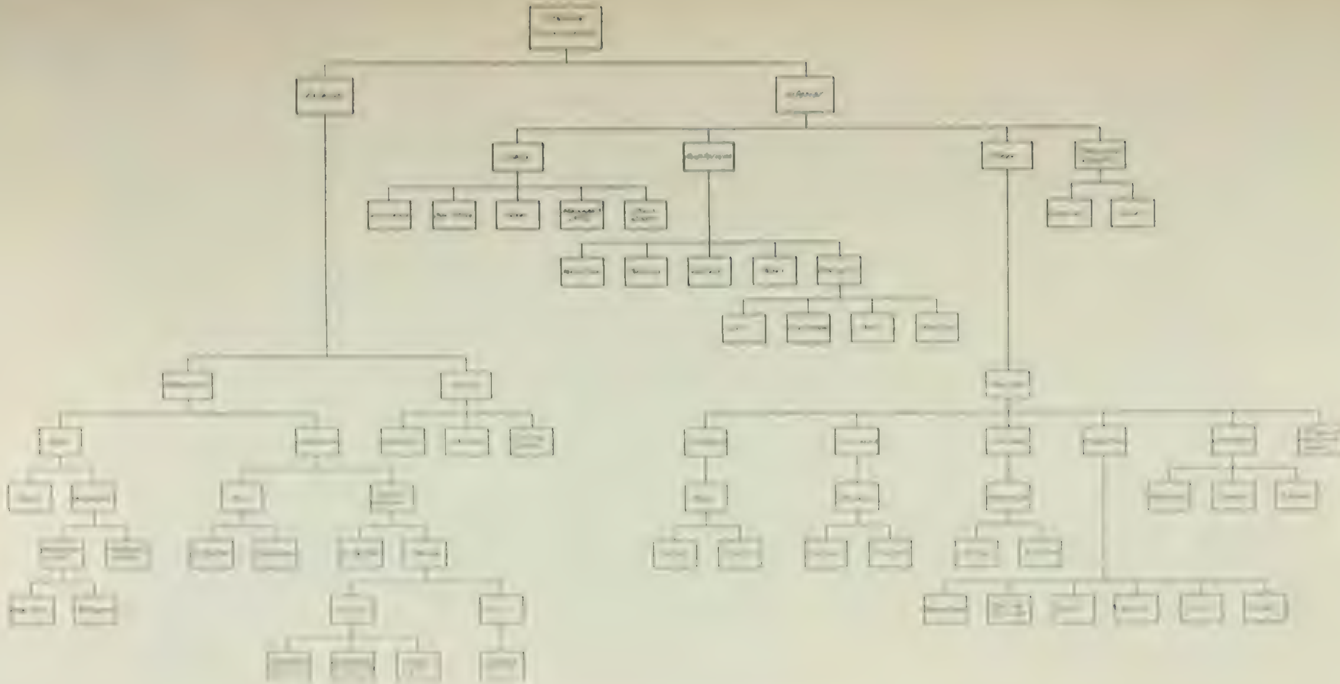

Fig. 1. Classification of theatre illumination

arc lamp effects; the other is the use of practically no other illumination than that afforded by the nearby street lighting standards. The large foreign theatres, and the theatres of the better sort in this country, are examples of the latter instance (fig. 2); while the smaller and cheaper vaudeville houses (figs. 3, 4, and 5) particularly in this country illustrate the former extreme. A feasible explanation for such divergence in practise is to be found in the fact that the large foreign theatres are assured of financial support by royal patronage and therefore have no need for exterior attraction lighting. The latter comparison of

Fig. 2.—Imperial Opera House, Vienna, Austria.

two classes of theatres is of course very antithical; but it indicates how radically different the exterior illumination of theatres may be treated in various localities and under different commercial and artistic conditions.

At this point the attention of the illuminating engineer should be directed to the practise of disfiguring theatre exteriors by signs and other objectionable forms of attraction lighting. To no small extent it devolves upon the illuminating engineer to stem the progress of possibly too rampant tendencies toward an obnoxiously glaring treatment of this phase of illumination.

The word "attraction," for want of a better term, has been used to describe the exterior illumination of small theatres, particularly the cheap vaudeville houses. "Attractive" was not used because such lighting is generally abnormally unattractive

and sometimes grotesque. It often consists of lighting units adapted to all forms of glaring, advertising, and alluring features on the outside of the playhouse, primarily for the purpose of attracting the attention of the passing, prospective patron. Signs (figs. 3, 4, and 5) both inert and animated are used in various forms and ways for announcing the programs of the

Fig. 3.—The Crystal Theatre, Milwaukee, Wis.

evening and for producing flashing and kaleidoscopic effects to induce the public to direct their attention toward the theatre.

Having accomplished this purpose, the decorative illumination effects on the exterior are dependent upon as a further magnetic influence on the unwary passerby. These decorative effects are accomplished by almost innumerable variations of studding the

facade and frontal exterior with incandescent lamps. The same psychological effect might as effectually, and more artistically, be obtained through the medium of concealed light sources playing upon the architectural features and bringing out in bold relief the details against the surrounding darkness. Fig. 5, a picture of the front of the Butterfly Theatre of Milwaukee, illustrates the former method; it shows the use of studded small, multiple series, tungsten lamps.

Fig. 4.—The Orpheum Theatre, Milwaukee, Wis.

One proposition presented to the management of this theatre for consideration was that shown in fig. 6, where units of sufficient size, character and number were to be concealed at various points behind the wings of the butterfly and at other places, so as to illuminate the background and certain portions of the facade, allowing the butterfly and other parts to become silhouetted against this highly illuminated background.

An exterior of this character could also be designed with the lateral towers projecting somewhat in front of the rest of the facade, with variations of tower and castle effects, so as to allow the foreground and portions corresponding to the butterfly to be brightly illuminated, by means of projectors or search-

Fig. 5.—The Butterfly Theatre, Milwaukee, Wis.

lights, against a darker background; this effect is largely produced in a different way by the present illumination of the Butterfly Theatre, shown in fig. 5. Or it might be accomplished by flooding the entire front of the building by means of projectors stationed at various points and heights in the towers, the towers themselves being uniformly illuminated from cornices ad-

vantageously placed so as to allow the downward distribution of illumination over their entire surface.

Utility lights are used on the exterior of theatres for the purpose of securing just the necessary illumination under the porticos, and on the street in front of the theatre after the performance has begun when the "attraction" lighting can not be used to great advantage, for the purpose of calling cabs by means

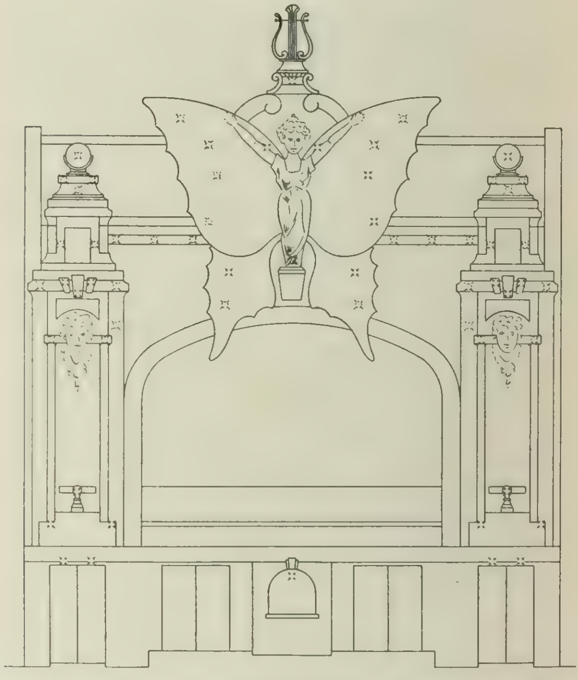

Fig. 6.—Butterfly Theatre (Milwaukee) scheme of lighting the facade by concealed lamps.

of talking signs or other contrivances, and in some cities for the purpose of signalling to the street car trainmen when the performance is about to terminate, in order that the train schedule may be adjusted.

While the illumination of the exterior of a theatre is interesting on account of its various phases, it is with the interior that the illuminating engineer is most concerned. There he can exercise to the greatest degree his ability and ingenuity and

cooperate most satisfactorily with the co-workers in the other allied branches of science and art.

In the past it has been customary to illuminate the interior of an auditorium by means of a large central chandelier of many units and an arrangement of bracket units along the front edge of the balconies, the whole scheme being augmented by incandescent lamps studded along the outline of the architectural features of the ceilings, domes, arches or balconies. Such installa-

Fig. 7.—Imperial Opera House, Vienna

tions are generally criticizable for their lack of consideration of the other branches of science previously mentioned. Intense glare from unscreened light sources of high intensity placed within the range of vision is usually evident. This method of treatment of the problems of theatre illumination has caused much discomfort, many headaches and severe eye strain to the patrons of the theatre who come there to be comfortably entertained. These installations utilize, practically entirely, direct illumination. They are illustrated in figs. 7, 8 and 9.

In the illustration of the Majestic Theatre, Milwaukee, fig. 8,

the studded lights along the frontal edge of the balcony and gallery are, on account of their locations, well above the lower edge of the vertical railing, and on account of the relatively flat curve of the contour of this edge of the balconies, are not as objectionable as might be expected, because they come within the range of vision of relatively few, besides the actors. Besides these lights, and the relatively low intensity sources shown on the ceilings of the balconies, this auditorium is illuminated by a central ceiling arrangement; no units are placed on the fronts of the boxes or the proscenium arch. Series of illuminometer readings taken

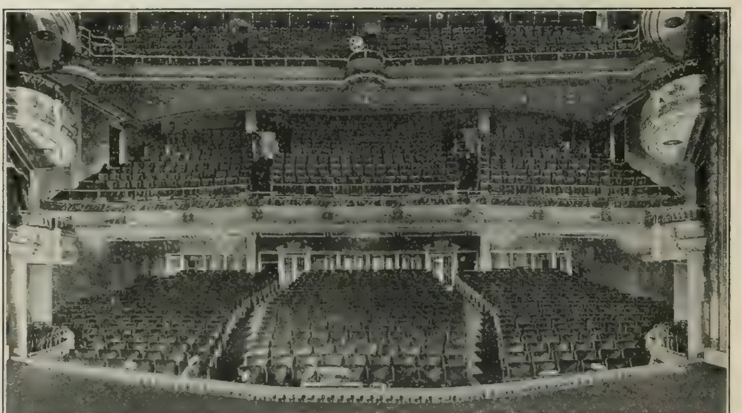

Fig. 8.—Majestic Theatre, Milwaukee.

in this theatre, however, show the effect of the non-uniformity of illumination from sources entirely in front of the deep overhanging gallery and balcony. In other interiors of this kind, on the other hand, the glare effect of the balcony and gallery units must be considerable.

In the Chicago Auditorium (fig. 9) the major part of the illumination for its main floor is supplied from the large arches which support the superstructure of the building; these are studded with a large number of incandescent lamps which, assisted by the gilded or gold-leaf decorations of these arches, produce quite effective illumination for those seated on the main floor; but in the galleries, however the glaring effect of

these intensely illuminated golden arches, almost directly in line with the stage, is very objectionable.

The foregoing illustrations and descriptions, as well as those following, are presented in this paper for the purpose of exemplifying existing typical installations found in various parts of the world and the results obtained in actual illuminations; not with any intention of entering deeply into the critical or argumentative side of each particular problem.

In a recent installation designed for the Pabst Theatre in Milwaukee, mature consideration was given to the features

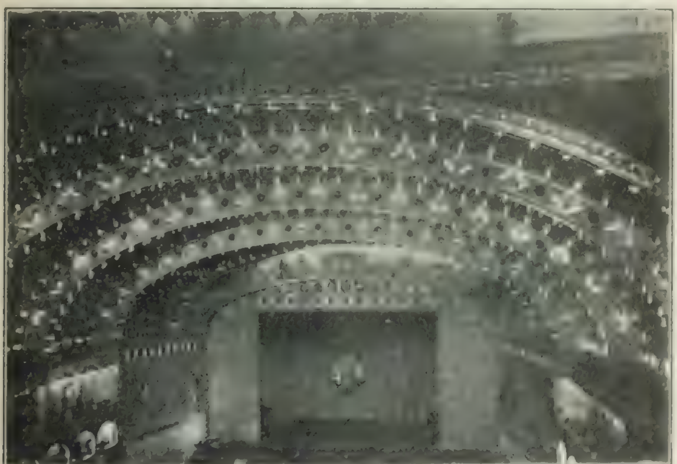

Fig 9.—Chicago Auditorium

mentioned in the introduction of this paper. It was decided that indirect illumination would solve the greatest number of problems arising in that playhouse. It was, however, necessary to contend with several very disadvantageous conditions, including the color and texture of the seats and floor coverings, which were dark red plush upholstering and Wilton carpet respectively, and the color of the walls and mural decorations, which also consisted largely of reds and terra cottas. The lighting was necessarily planned to conform to the existing conditions in the theatre, which was constructed in 1894.

Here, parenthetically, two points should be mentioned, such

decorative effects are, of course, almost entirely governed by the tastes of the architects, owners, and managers, and vary materially, due to nationality, individuality and geographical location. Again, it is to be expected that the decorative and architectural features of the theatres in France, for instance, will differ radically from those in Germany and America; and that

Fig. 10.—Foyer of Pabst Theatre, Milwaukee.

the typically American theatre may differ materially from a theatre like the Pabst, which is German-American in its ownership, management, attractions and patronage, being given up largely to the performances of a German speaking stock company, concerts and lectures.

Another disadvantageous condition encountered was the relatively short time in which to thoroughly develop this installa-

tion, on account of delayed decision to proceed with the work, occasioned by absence of members of the management of the theatre until a late date, with the result that is still hardly beyond the experimental stage.

In deciding upon the above type of installation, it was realized that certain mechanical difficulties were to be overcome, owing to the use of inverted dome type fixtures, in the placing of these units under the balconies and on the ceilings of the boxes; and

Fig. 11.—Auditorium central lighting unit with reflector disk, Pabst Theatre, Milwaukee.

in designing them so that their interior units would not be perceptible from any of the upper strata of seats. If the last mentioned difficulty were not overcome one of the main purposes of this form of illumination would have been thwarted. Figures 10 to 13 indicate how some of the aforementioned conditions were met in lighting this theatre.

One of the factors, which had considerable weight in the decision to make this theatre's illumination entirely of the indirect type, was the architectural features, especially in the foyer.

(fig. 10) the style of which is historically interesting from an illuminating engineering standpoint. The ceilings were arranged with dome-like depressions, having inner-coved edges, in which incandescent lamps were originally used without reflectors. While this arrangement was artistically pleasing, it was, of course, an inefficient type of installation and had to be augmented by the installation of studded, incandescent lamps at points which controverted the entire object and effect of the cove lighting installation. These architectural features were, however, particularly adaptable to the installation of indirect lighting units which are now installed. The latter units accomplished, efficiently and artistically, the effect originally desired and dispensed with all visible sources of light.

To preclude the possibility of obstructing the view of people

Fig. 12.—Lighting units in boxes of Pabst Theatre, Milwaukee.

seated in the rear of the balcony by the presence of the units hung near the front of the gallery, the lighting units were designed relatively deep and each suspended close to the ceiling by means of three slender silken cords. They were thus placed out of the range of vision; their interiors were well concealed, and the clumsiness of the short chain suspension was eliminated.

On account of the low ceiling heights, possible interference with the head-dress of the occupants, and the undesirability of having the interiors of the units in view, the fixtures in the boxes were designed as shown in fig. 12 and the detail drawing shown in fig. 13, with satisfactory results as to location, height and pleasing artistic effects from the "sky" illumination.

In order to comply with the rules of the National Board of Fire Underwriters with reference to fixture insulation and to avoid the use of an insulating joint and a large, clumsy canopy on this unit, the arrangement as shown in fig. 13 was adopted. All parts of this fixture which are subjected to electric stress

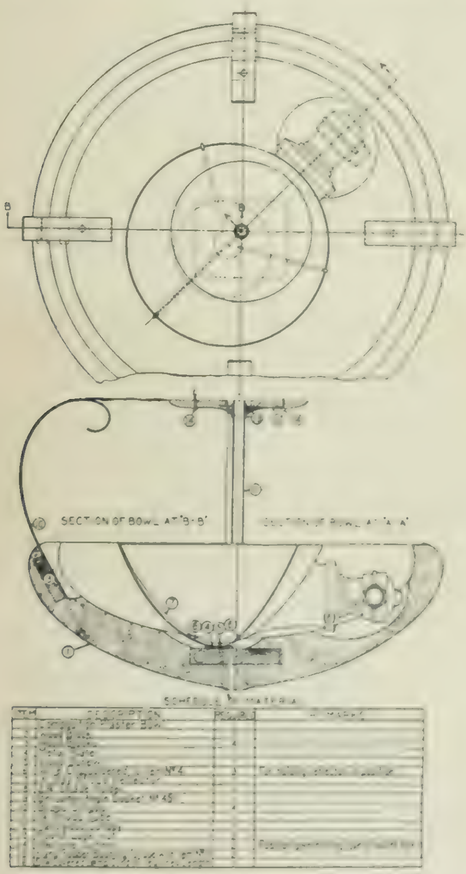

Fig. 13.—Detail drawing of lighting unit in boxes of Pabst Theatre, Milwaukee.

are insulated, and all grounded parts are insulated and removed from the wiring. The small brass tube conducting the cord from the ceiling to the interior is used merely as a guide to keep the cord in position.

The major part of the illumination in the auditorium of this theatre emanates from a large, inverted dome-shaped, indirect unit (fig. 11) suspended from the center of the domed ceiling at approximately fifty-five feet from the main floor. The lamps in this unit are arranged so that a majority of the higher wattage lamps are in the half nearest the stage; the smaller lamps are in the half toward the gallery, and a vertical sheet iron shield is placed across the diameter parallel with the face of the gallery. This arrangement produces an asymmetrical distribution of light from this unit, without noticeable effect on the ceiling.

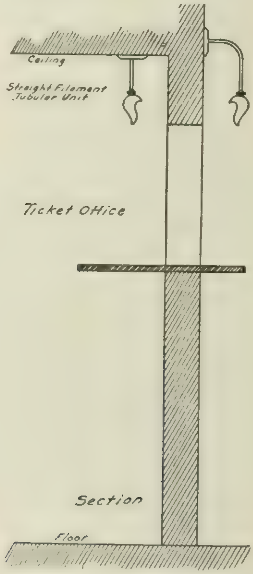

Fig. 14.—Sketch of lighting unit in ticket office of Pabst Theatre, Milwaukee.

More than half of the light thereby reaches the main floor and less than half is intercepted by the gallery which is close to the reflecting surface, thereby tending to produce a more uniform distribution throughout the house. It also overcomes the possibility of actually seeing the interior of this unit from the topmost seats of the very high and steep gallery.

The absence of any light source within the range of vision was deemed of particular importance because of the relatively great number of concerts and lectures which are given under the

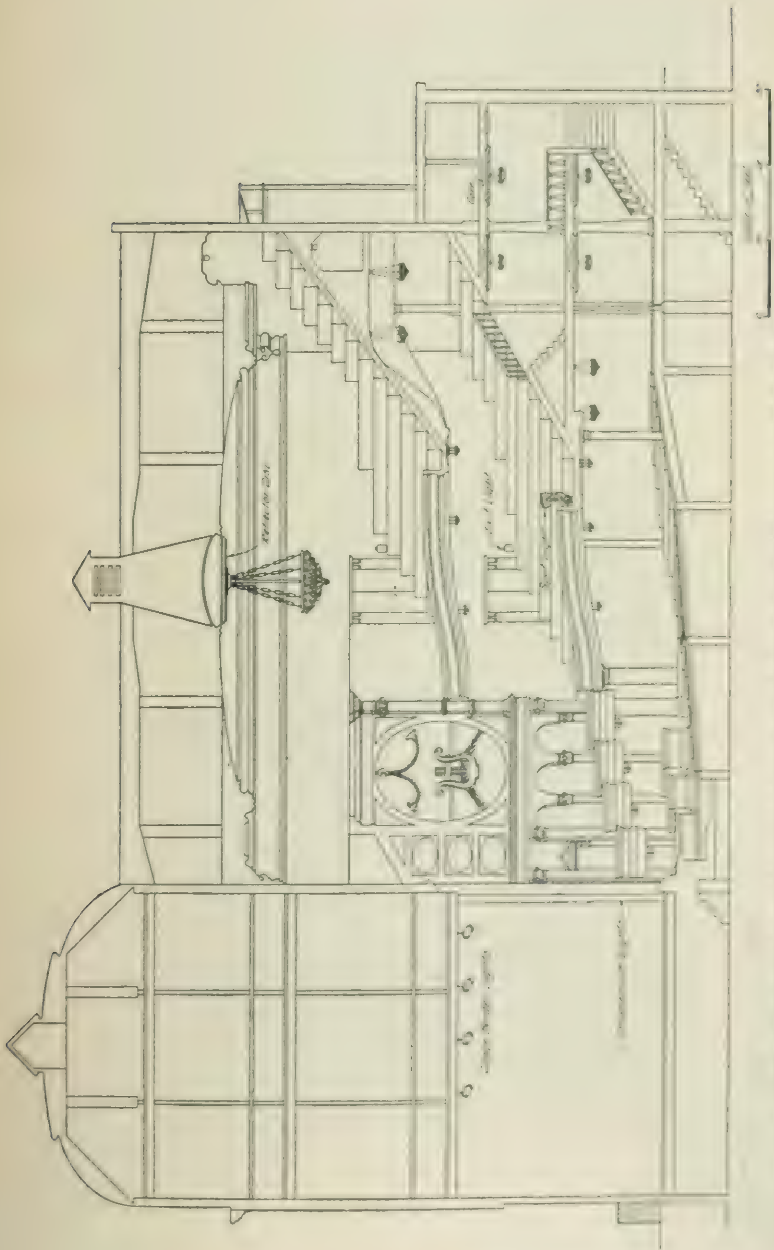

Fig. [illegible].—Vertical section showing arrangement of interior lighting units of the Pabst Theatre, Milwaukee.

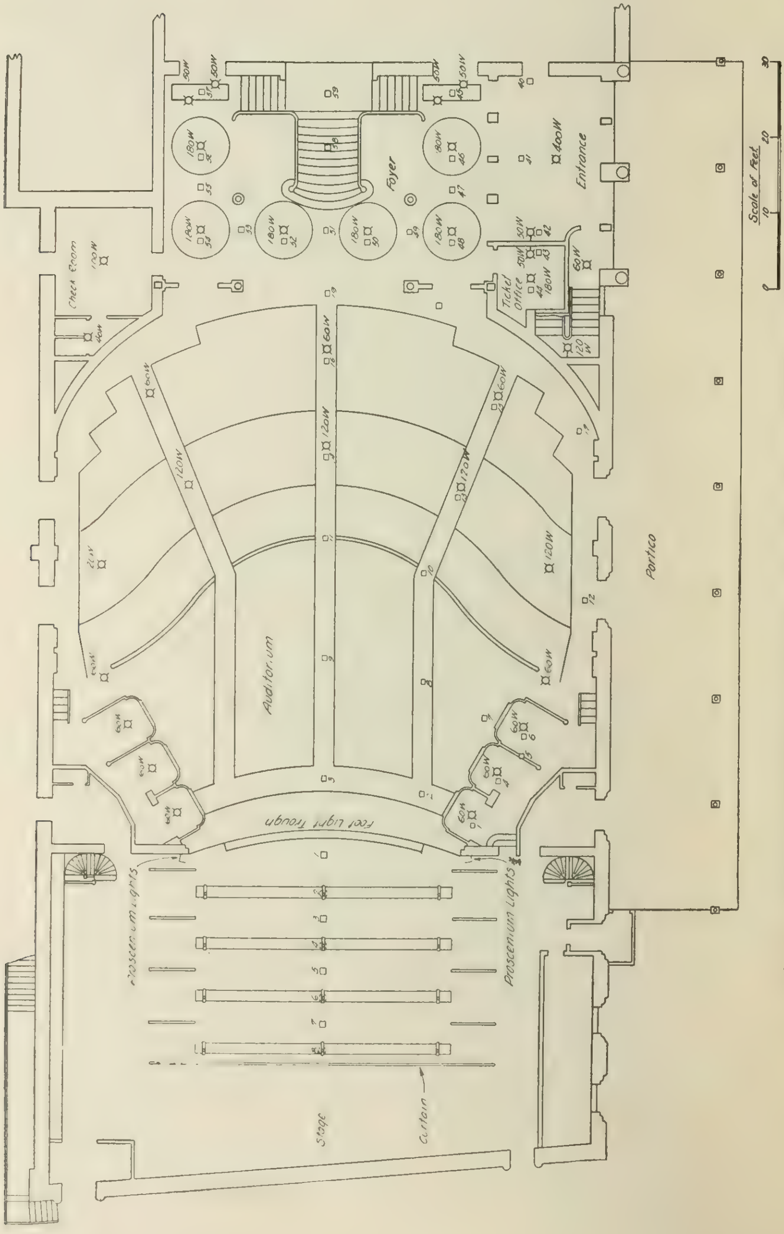

Fig. 16.—Diagram of main floor of Pabst Theatre showing illumination test stations.

auspices of this management and the resultant long periods throughout which the audience would be subjected to whatever influence might be occasioned by the lighting units.

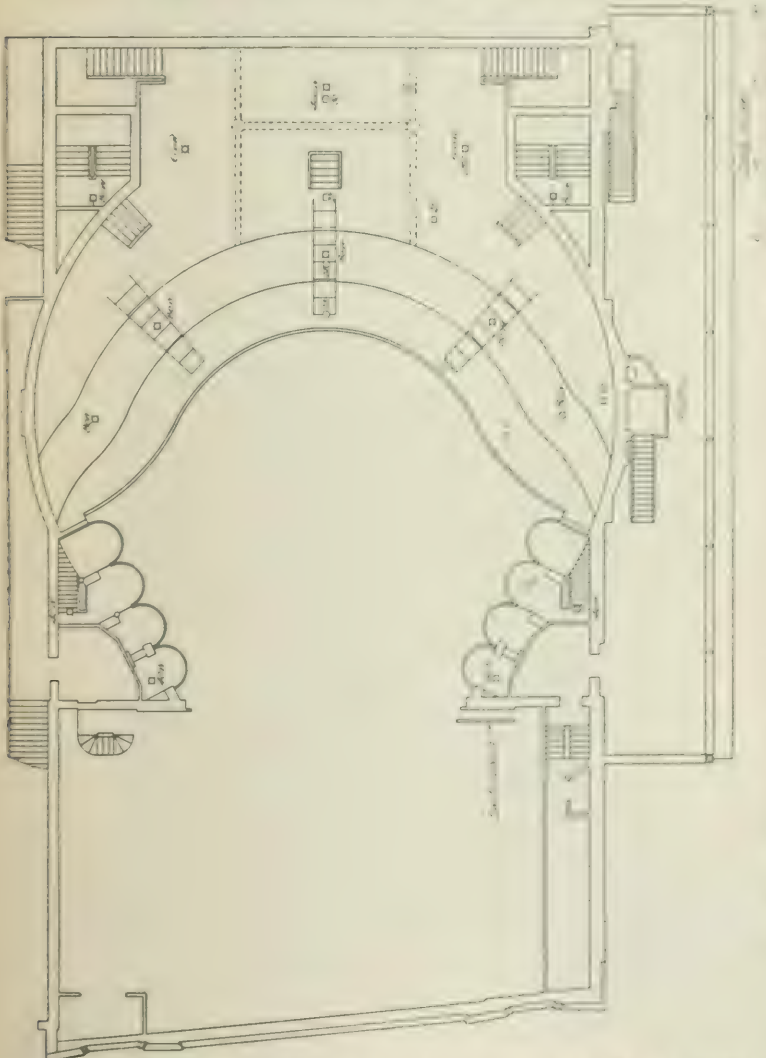

Fig. [illegible]. Diagram showing illumination test stations on balcony of Pabst Theatre, Milwaukee.

A super-dome, used as a ventilation opening, at the apex of the domed ceiling, was included in the planning of the old, original central unit, and from this was suspended a prismatic crystal

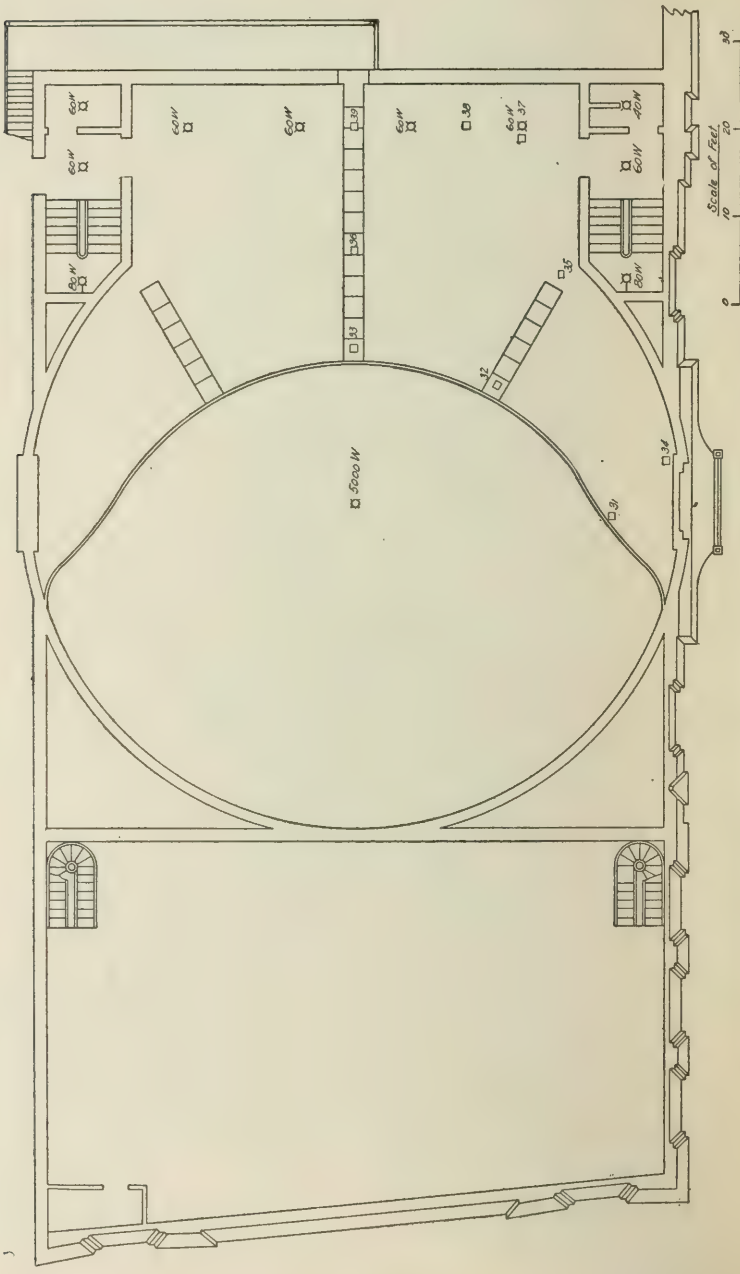

Fig. 18.—Diagram showing illumination test stations on the gallery of Pabst Theatre, Milwaukee.

fixture which only partially obscured the structural details above. The elimination of this fixture left an opening which could not be utilized for the reflection of light and which necessitated the development of the reflector disk shown in the illustration. The disk is placed far enough below the opening to allow sufficient ventilation space.

The scheme of concealing all light sources in this theatre was, for the sake of completeness, utilized in the entrances and in the ticket office. Just within the entrance a large indirect unit was installed. The accompanying illustration (fig. 14) of the arrangement of straight filament, tubular lamps with corresponding reflectors shows how a flood of light is provided on the ticket office window ledge without the use of visible sources.

The various photographs which were secured for the purpose of illustrating this paper were not taken with any idea of uniformity of exposures or conditions, or to represent in any way the actual illumination secured in any instance; they were taken indiscriminately at various times and places, and by different photographers, under daylight, artificial light or the self-illumination, without special regard for the local features. To illustrate the details and appurtenances utilized in producing the illumination effects was deemed more important. In the views of interiors of theatres illuminated by the indirect system—in the Pabst Theatre, for instance—the photographic difficulties encountered in attempting to bring out the actual conditions of illumination existing on the lightly tinted, intensely illuminated ceiling and the dark red carpets and seat coverings are recognized. The illumination effects have sometimes been sacrificed in the printing of the photographs to their main purpose of illustrating the details of the design of the installations.

Figs. 15 to 18 inclusive show diagrammatically the entire interior lighting scheme of the Pabst Theatre. Figs. 16, 17 and 18 show the location of illumination test stations. A table of illuminometer readings taken in this theatre is appended to this paper.

Without attempting to explain the possible psychological effect of indirect illumination, or to enter into the argument concerning the relative quantity of direct and indirect illumination required under varying conditions, which subject is now being

very ably investigated by a member of the Illuminating Engineering Society, the authors wish to express the opinion which is probably held by those who have utilized much indirect illumination, that, after the first impression of dimness received by any person upon introduction to this type of illumination, due probably to the existing vogue of over intensity and glare, the results are in general satisfactory with less foot-candle intensity

Fig. 19.—Majestic Theatre, Fort Worth, Tex.

of indirect illumination than of the other type as ordinarily installed.

The interior views of several other theatres, auditoriums and lobbies illuminated by the indirect system are shown in figs. 19 to 23. Attention should be directed to the coloring and texture of the interior decorations of these theatres, especially the light, efficient tinting of the Butterfly Theatre, (fig. 21) which is a contrast to the dark tone of the Pabst Theatre interior. The direct lighting units shown in the pictures of the Majestic Theatre of Fort Worth, Tex., have never been used inasmuch the indirect units alone provide satisfactory illumination. In the Plaza Theatre of Chicago the proscenium arch is illuminated by mir-

rored reflector units sunk into the cornice at either end of the arch.

Incidentally there are now in the planning several theatres whose illumination will probably be entirely of the semi-indirect type In those installations inverted, diffusing, glass, dome-shaped or urn-shaped units, suspended similarly to the usual indirect fixtures will be utilized. From these units a portion of the light will reach the plane of illumination through the translucent glass while the major portion will be reflected indirectly from the ceil-

Fig. 20.—Rear of auditorium, Majestic Theatre, Fort Worth, Tex

ing. It is hoped that this type of installation will produce pleasing and satisfactory results.

Under emergency lighting are classified all the lights in the auditorium which do not bear directly upon the performance, and which are of course least interesting from an illumination standpoint. But these must be taken into consideration by one who plans the illumination for a thoroughly equipped theatre. They will receive but casual mention in this paper. They include exit lights, which must be red, to indicate every point of exit, and are so connected and constructed, as to be as reliable

as possible. For this kind of lighting ordinary wax candles are sometimes placed behind red glassed, recessed inclosures near the exits. Storage battery equipments and separate feeders and switches, operated from both box office and stage, are also used. Several Chicago theatres use gas only on the exit lights and others use sperm oil lamps. In some indirect installations a red light is wired on a separate circuit in a unit nearest the exit.

Under this heading is also included the so-called panic lights, which are required for use under conditions similar to those which existed at the Iriquois Theatre fire a few years ago.

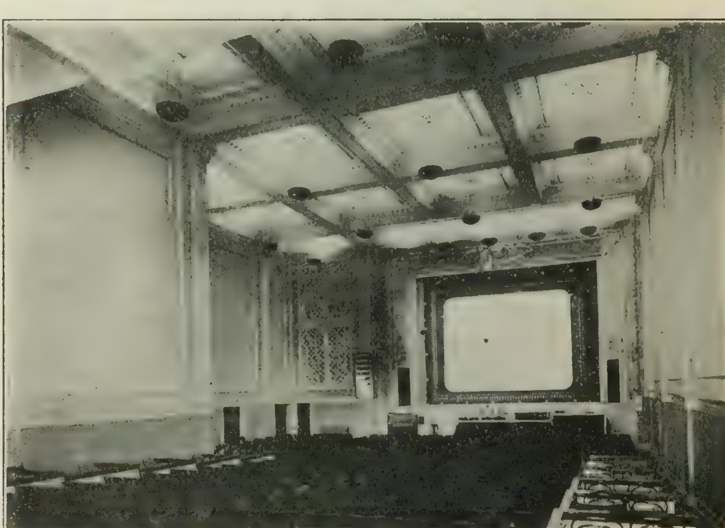

Fig. 21.—Butterfly Theatre, Milwaukee.

Their character and installation is controlled by the National Board of Fire Underwriters. Those in the Pabst Theatre are shown at the foot of the statuary group above the proscenium arch in the photograph (fig. 11) of the auditorium central unit and reflector disk. They should be controlled from the box office and the stage, but not from the stage switchboard, by means of single or double-pole switches, connected in multiple so that they may be turned on or off, at both, or either points, but not in the manner of a three-way switch connection; because if the stage electrician should turn them on in case of emer-

gency from the stage and then the box office attendant should also decide to push the switch, this second operation would counteract the first and extinguish the lights which were, unknown to him, already lighted.

Stair, passage and fire-escape illumination should also receive serious consideration with the other classes of emergency units. In the dark stairways leading to the gallery of the Pabst Theatre, the unit shown in fig. 24 is installed. Two lamps are used, where one would give ample illumination, to provide a

Fig. 22 —Plaza Theatre Chicago

greater factor of safety than that afforded by a one-light fixture, by embodying the improbability of two lamps burning out simultaneously; or, to state the reason differently, to remove the possibility of having part of the winding stairway darkened in a time of great emergency by the burning out of a single lamp.

For the sake of economy, there are also installed at various points throughout the auditorium working lights for the use of house-cleaners and attendants. Such lights should be on a separate circuit conveniently controlled from the auditorium;

they may or may not be a part of the general illumination scheme. In the Majestic Theatre of Milwaukee the central unit in the five-light groups, under balcony and gallery, are used in this way. In the Pabst Theatre, a separate circuit of special lamps for this purpose is provided. In several Chicago theatres portable floor standards, with one or more lamps each are used, being moved from point to point by the house-cleaners, and connected to base board of floor receptacles by long cords.

One other detail to be considered in auditorium illumination,

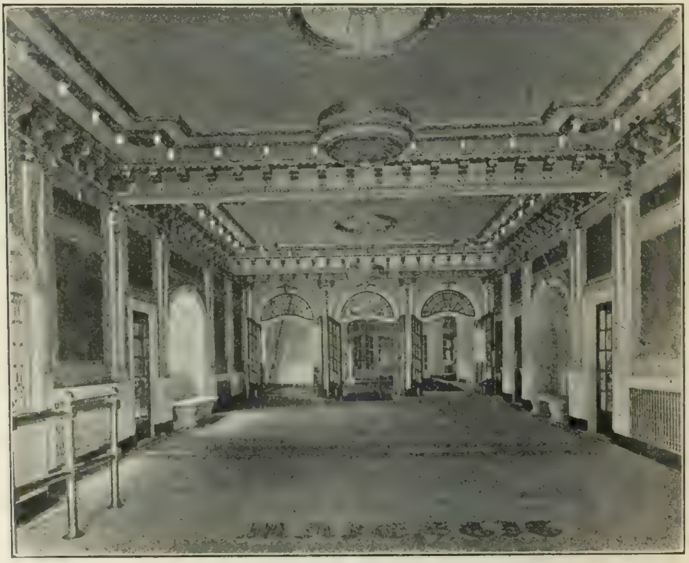

Fig. 23.—Foyer of Majestic Theatre, Fort Worth, Tex.

especially in cities where this subject has been treated by the common councils, is the requirement by city ordinances that enough lamps shall be kept lighted during the entire exhibition in theatres, for the discernment of the movements of the audience. This is usually accomplished by arranging one or more of the lamps in each unit to be controlled separately so as to provide just sufficient illumination for the ushers, and to comply with the spirit of the ordinance, without producing light enough to interfere with the distinctness of the views upon the screen, or with other stage effects. It is possible, in theatres of this

character to graduate the illumination from relatively high intensity at the rear of the auditorium—even up to full intensity—to a relatively low value at or near the stage.

On the stage there are so many accessories, lighting effects

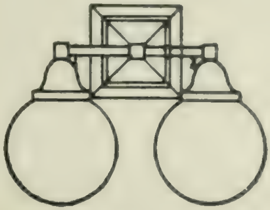

Fig. 24.—Sketch of stair lighting unit, Pabst Theatre, Milwaukee

and miscellaneous appurtenances used for spectacular or strictly illuminating purposes with intermeshing indiscrimination that it is difficult to select the parts of the equipment which may safely be predicted to interest the illuminating engineer as theatre illumination, and segregate it from that portion which could be designated as "theatrical" illumination. However, as all equipment utilized by the house electrician, or coming under his jurisdiction, for the purpose of producing lighting effects for

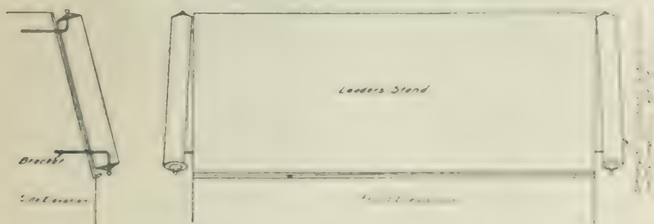

Fig. 25.—Orchestra leader's lighting equipment Majestic Theatre, Milwaukee.

or at the stage must have an important bearing upon the efforts of the illuminating engineer who designs the lighting equipment of a theatre, it will all be touched upon in this paper for the purpose of eliciting discussion.

But before dealing with the lighting of the stage, there is one important detail of theatre illumination which deserves attention—the lighting arrangement for the orchestra. Units for the use of the musicians should produce sufficient extremely lo-

calized illumination on the score, with a minimum interference with the effect of the "dark" scenes. This is usually obtained through the medium of opaque, cylindrical enclosing envelopes of metal, with a longitudinal or transverse slit for the emission of the light; its usefulness, convenience and effectiveness can be augmented by an easily operated, quiet, slit-adjusting feature, which will provide a maximum or minimum amount of light, as required. The external finish of the enclosing envelopes may be dull green or of an equally non-lustrous coating.

In the diagram of the orchestra leader's illuminating equipment (fig. 25) designed for the Majestic Theatre, it will be noted

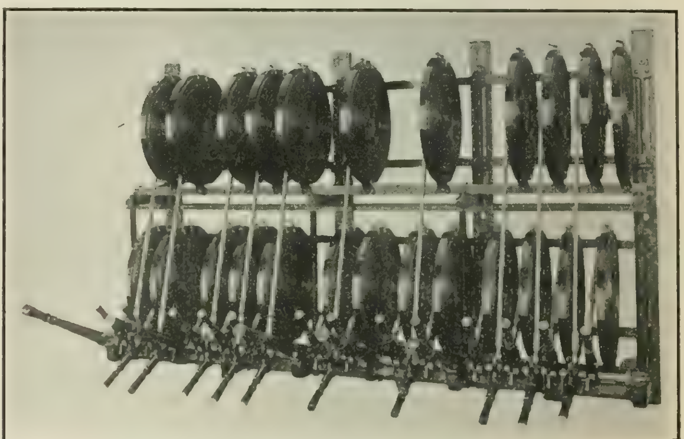

Fig. 26.—24-plate, interlocking theatre dimmer.

that two units flood his stand from the sides instead of the single unit on top, as used by the other musicians. The equipment shown in this illustration has displaced the one shown in the interior view of this theatre, (fig. 8), which projected objectionably above the front edge of the stage.

On the stage is, of course, always located quite an elaborate, ingenious and more or less complicated switchboard, by means of which complete control of all the possible stage illuminating and spectacular effects is secured by the house electrician. Master and sub-master switches are mounted on this switchboard, by which all or a part of the circuits can be instantaneously dis-

connected or connected; switches by which the "reds," "whites" and "blues" or "ambers" of the footlights, borders and proscenium lights can be controlled are also included—all necessary and convenient switching and measuring devices should also be installed—the entire dimming equipment, with its interlocked handles so arranged that one portion of any section of any color can be individually increased or decreased in brightness,

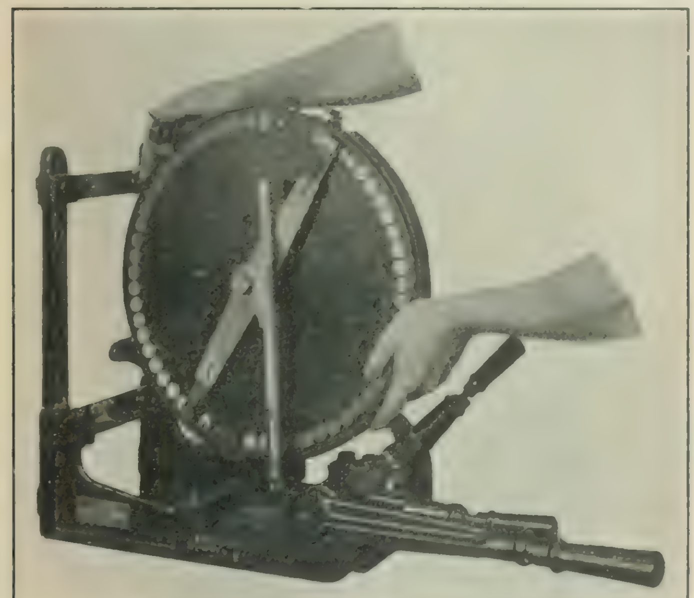

Fig. 27.—Detail of interlocking type dimmer.

or the entire group of any one color or section operated simultaneously by means of the master lever, should also be mounted on or conveniently near this switchboard. Slow moving, grand master levers, which will operate the entire dimming equipment simultaneously, are sometimes installed, but are seldom used in the average theatre.

Several existing arrangements of dimmer plates, levers and switchboard equipment, exhibiting the varying requirements and interesting detail of this important phase of stage illumination are shown in figs. 26 to 29.

A problem which confronts designers of dimmers at the present time is the transition from the use of carbon lamps in footlights and proscenium lights and possibly in the borders to the use of the highly developed and more rugged type of the up-to-date tungsten lamp. At least one theatre in Chicago is entirely equipped throughout the stage with tungsten lamps. The peculiar sensitiveness of the tungsten lamp to the steps in the resistance of the dimmers has occasioned a serious investigation of this problem, with a view to obtaining data on the requirements and the proper adjustment of steps and resistance.

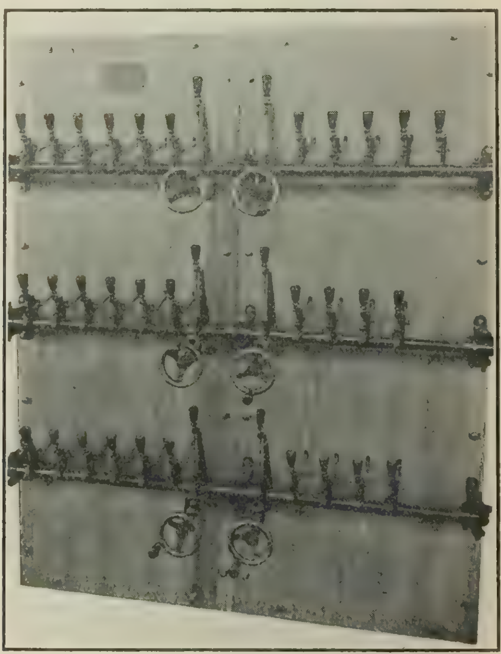

Fig. 28.—Typical hand operated dimmer switchboard installation.

The question of whether the lamps should be dimmed along the gradient of a straight line or along some curvilinear locus has also arisen. In this connection it is possible that the most effective gradations in the brightness of the lamps might be secured by adherance to a locus of diminution which would take into account Fechtner's law and other factors, physiological and psy-

chological, which effect the relative efficiency of vision under high and low intensities of illumination. In other words, it must be expected that a step in the dimming, which is comparatively unnoticeable at normal or bright intensity, might be more or less so at low intensity, due to the effect of these laws.

Still another problem with which the designer has to cope is the development of dimming equipments for use in theatres supplied only with alternating current, and using tungsten lamps.

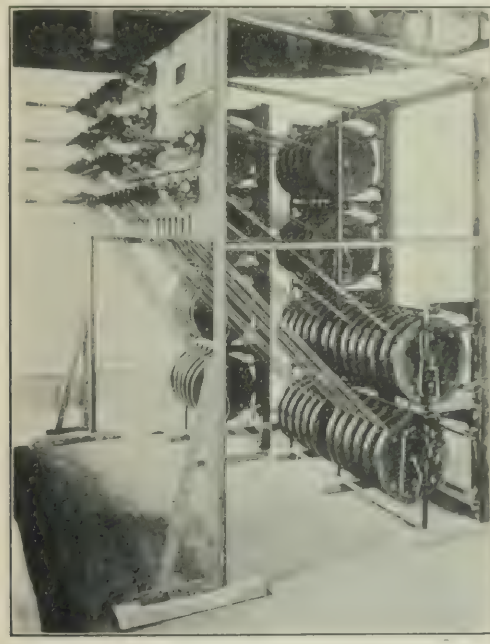

Fig. 29.—Dimmer at Forest Theatre, Philadelphia.

One general common characteristic between footlights, border lights and proscenium lights is that they are composed of groups of red, white and blue lamps, which can be utilized through the dimmers in endless combinations, to produce illumination of varying color and intensity. The footlights are located approximately on the stage floor level at the front edge; the proscenium lights behind the vertical, lateral edges of the proscenium arch; and the border lights above the stage at ad-

justable heights among the flies in sufficient numbers and lengths to admit of the illumination of the entire stage from the front to the rear.

Illuminometer readings, both in the vertical and horizontal

Fig. 30. Curve showing intensity of stage illumination produced by foot, border and proscenium lights, Pabst Theatre, Milwaukee.

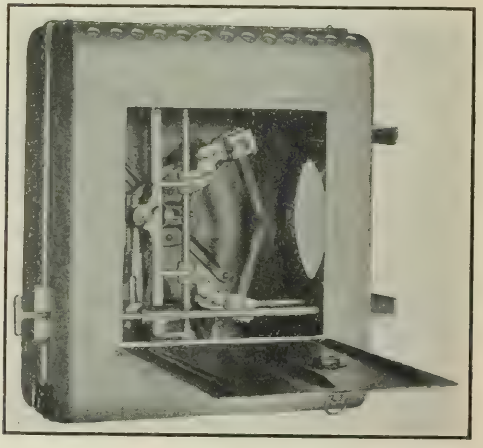

Fig. 31.—Lens lamp showing proper position of carbons for alternating current circuit.

planes of illumination, were taken from the front to the rear along the center line of the Pabst Theatre stage, when illuminated under normal operating conditions, using the "whites" of the foot, border and proscenium lights. These readings are presented in the form of curves in fig. 30. Attention should be directed to the high intensity in the vertical plane at the front

of the stage, under the powerful influence of the footlights and proscenium lights. These lights, of course, have less influence on the readings taken at the rear of the stage. The horizontal intensity is comparatively low at the front of the stage, but it gradually increases as the rear of the stage is approached, due to the superimposition and accumulative effect of more and more borders, the directive influence of the reflecting surfaces of the borders acting toward the rear, as shown by the border arrangement in the vertical section drawing of the Pabst Theatre, fig. 15.

Fig. [illegible]—Flood light mast

The influence of the footlights on the distribution curve is, of course, governed by the shape and design of the reflecting surface. The trough at the Pabst Theatre has perhaps less than a normal effect on the rear half of the stage, because the entire equipment of lamps and reflecting surface must be below the level of the stage floor, in order that it may not interfere with a level stage effect when it must be covered up for large orchestral concerts, or for lectures. A great deal can be accomplished by concentrating some illuminating engineering skill on

the shape and surfaces of the footlight trough, or reflector. Certain steps are now being taken, in fact, toward the development of new features in connection with footlights.

A matter entirely independent of the fragility of the tungsten lamp, but effecting its use in the foots, borders and proscenia, is the difference in color and quality of illumination produced by it, as compared with the carbon lamp and the resultant difference in appearance of the actor who has made up in the dressing room by carbon lamp light and appears on the stage which is illuminated by tungsten lamp light.

Innumerable spectacular and illumination effects can be secured through the medium of the various types of lighting appa-

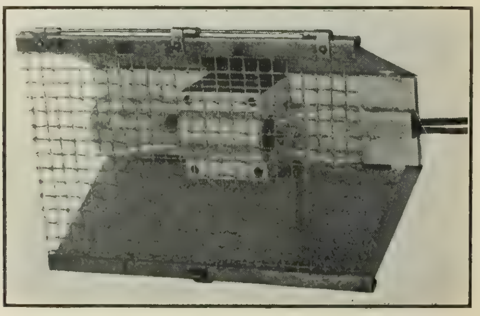

Fig. 33.—A unit section of strip light.

ratus, which can be placed under the general classification of projectors. This class includes the spotlights or lens boxes (fig. 31) which are used on the balconies or on the stage for concentrating light of great intensity on restricted areas; flood lights, or Olivettes, (fig. 32) or arc lamp contrivances used on the stage for less intense illuminations or less restricted areas; bunch lights, or clusters of incandescent lamps backed by reflectors with more or less projecting and directive qualities, used on the stage for soft and more or less localized illumination; strip lights,[1] (fig. 33) or short, portable rows of incandescent lamps used on the stage for certain localized effects; the stereoptican or projection lantern, which must usually be provid-

[1] An interesting use of adjustable strip lights suspended from the flies and used as side lights is described in an article on "Lighting of the Stage of the Berlin Grand Opera House", *Illuminating Engineer*, Oct., 1911.

ed for at a convenient point in front of the stage, in the auditorium, in the balconies or galleries, where it can be used for illustrated lectures or for other purposes, and the moving picture machine, which must be carefully provided for under the very rigid requirements of the National Board of Fire Underwriters and the ordinances of some cities, and be useful for the production of certain realistic cloud and water effects in grand opera or spectacular drama.

Illuminometer readings were taken at the Pabst Theatre directly in the range of the spotlight operating from the balcony about sixty-four feet distant. There were found to be 83.3 foot-

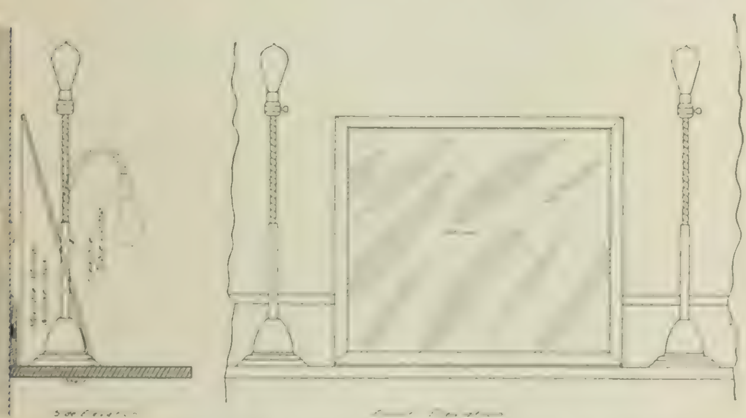

Fig. 34.—Lighting unit in dressing-room of Majestic Theatre, Milwaukee.

candles of illumination on the normal plane forty-eight inches above the stage floor. On the same plane 2.3 foot-candles were obtained from this same spotlight, adjusted for a flood-light, operating in the same location in the balcony, sixty feet distant. This is indicative of the relative effects obtained from the spotlight and the flood-light and of the extremely high intensity and glare which is utilized on the stage through the medium of the spotlight. The candle-power of the ray in the direction normal to the above plane, during the spotlight test, was equal to 3,400.

Each of the above-mentioned apparatuses have many interesting features in their use and construction but it must suffice in

this paper to present photographs of them with only brief discussion of most of them.

Another lighting accessory utilized and used on the stage of vaudeville theatres, is the program announcer. One of the "announcers" is shown in fig. 21. Those used in the Majestic Theatre of Milwaukee are located on both sides of the proscenium arch and consist of a box with an art glass, translucent, face toward the audience, in which a one letter "talking" sign is changed and

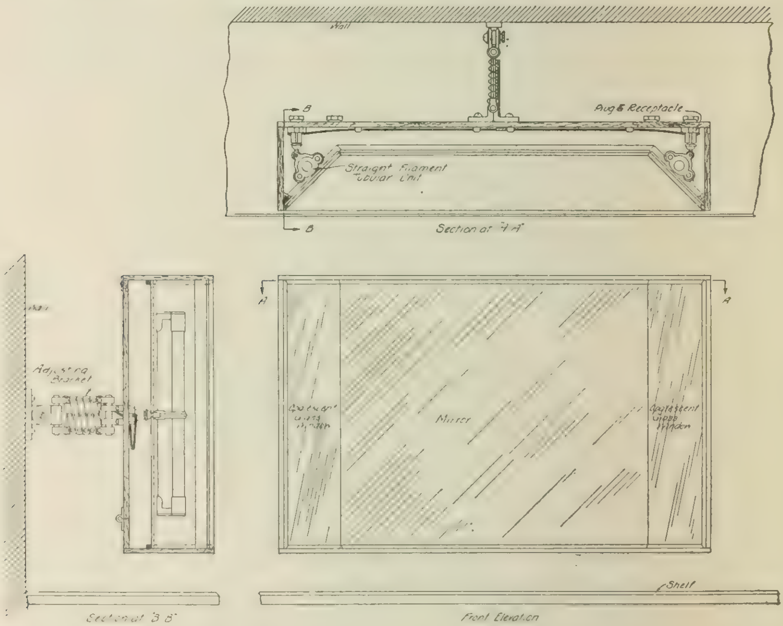

Fig. 35.—Lighting unit for dressing-room.

controlled to announce the items on the program by letters, by means of an ingenious drum controller containing positions for all letters and numerals. Another type of this form illumination is shown in fig. 22, where lights behind translucent glass signs illuminate the entire name of the item, or the identifying letter.

It seems from an inspection of the dressing rooms of an average theatre that not all the available ingenuity has been expended upon the arrangement of the lighting units in these rooms.

The majority of arrangements are crude and inconvenient in all or some particulars. Two of them are shown in figs. 34 and 35 to indicate the trend of practise in this direction. The arrangement used at the Majestic Theatre, Milwaukee, (fig. 34) has a portable box easel, holding the mirror at about twenty degrees from the vertical, which allows adjustment of the mirror in var-

TEST No 62
TEST MADE BY J.A.H
DATE 11/2/10
TIME 10 P.M.
C = 85'
L =
P = 36"
H =

LOCATION MILWAUKEE AUDITORIUM
MAIN HALL.

REMARKS: ALL LIGHTS ON, INCLUDING
THOSE OVER BALCONY.
WITH SCREEN LSR. K-32

	STATION No 1 SCREEN 58 VOLTS			STATION No 2 SCREEN 58 VOLTS			STATION No 3 SCREEN 58 VOLTS			STATION No 4 SCREEN 58 VOLTS		
	SCALE READINGS			SCALE READINGS			SCALE READINGS			SCALE READINGS		
	Er			Er			Er			Er		
	2.3			3.1			4.5			[illegible]		
	2.2			3.3			[illegible]			[illegible]		
	2.0			3.1			3.8			5.0		
	2.2			3.0			[illegible]			5.6		
	2.2			3.0			3.9			5.7		
	2.1			[illegible]			3.8			5.3		
	2.2			2.9			3.9			5.3		
	2.5			2.9			4.4			[illegible]		
	2.5			2.9			4.5			[illegible]		
	2.4			3.0			[illegible]			5.3		
AVERAGE READING	2.26			3.01			[illegible]			[illegible]		
E or F READING	.72			[illegible]			[illegible]			[illegible]		

	STATION No 5 SCREEN 58 VOLTS			STATION No 6 SCREEN 58 VOLTS			STATION No 7 SCREEN 58 VOLTS			STATION No SCREEN VOLTS		
	SCALE READINGS			SCALE READINGS			SCALE READINGS			SCALE READINGS		
	Er			Er			Er					
	7.5			7.6			4.3					
	7.3			7.4			[illegible]					
	7.0			7.2			[illegible]					
	7.0			7.4			[illegible]					
	6.2			7.2			[illegible]					
	7.0			7.0			4.3					
	7.0			7.6			[illegible]					
	7.6			8.0			[illegible]					
	7.8			7.9			[illegible]					
	7.0			7.5			[illegible]					
AVERAGE READING	7.04			7.47			[illegible]					
E or F READING	2.3			2.4			[illegible]					

FORM No 21 SHEETS IN ALL ___ SHEET No ___ TEST No 62

Fig. [illegible] A record form for illumination test data

ious directions, except the above-given angle, which, it is believed, would be advantageous. The lighting units are, of course, conveniently flexible, but under the conditions that they are almost certain to be used they are sure to be very objectionable from the standpoint of glare.

An arrangement which combines maximum adjustibility of

mirror, minimum of glare, sufficiency of illumination on all parts of the face and neck and security of the lamps from breakage or loss, is shown in fig. 35. All these units may or may not be supplemented by general illumination.

In conclusion, the authors wish to say that they found it quite impossible to treat the theatre illumination either very completely or exhaustively in a paper of this character. The subject is too broad to admit of any but a general discussion. But even as such, the authors hope it will elicit, in whatever discussion it may occasion, some valuable ideas and suggestions on this very interesting phase of illuminating engineering.

The acknowledgments and thanks of the authors are due especially to Mr. William Schwartzkopf for information pertaining to the Butterfly Theatre; to Mr. Charles Dietz of the Commonwealth Power Co., for information on several Milwaukee Theatres; to the National X-Ray Reflector Company for photographs of indirect illumination applications in Chicago and elsewhere; to the Cutler-Hammer Company and General Electric Company for illustrations of dimmers and other stage appurtenances; and also to the management of the Pabst Theatre Company, their architect, Mr. Herman Buemming, and their electrician, Mr. Sprenger, for their many kindnesses during the design, installation and test of the illumination equipment of this theatre.

APPENDIX.

Pabst Theatre (Milwaukee) Illumination Test Results.

Horizontal Illumination.

Station	Foot-candles	Station	Foot-candles
1	0.8	31	1.5
2	0.8	32	2.5
3	0.8	33	3.1
4	0.8	34	0.4
5	1.0	35	0.3
6	0.9	36	0.8
7	1.0	37	1.0
8	0.9	38	0.9
9	1.0	39	0.9
10	1.2	40	0.8
11	1.5	41	1.5
12	0.4	42	0.9
13	1.6	43	7.5
14	1.5	44	1.2
15	4.9	45	0.3
16	6.0	46	0.6
17	1.2	47	0.8
18	0.8	48	0.9
19	3.4	49	1.1
20	0.7	50	1.0
21	1.0	51	1.0
22	1.6	52	1.0
23	2.1	53	1.2
24	1.0	54	1.0
25	0.4	55	1.3
26	1.4	56	1.1
27	1.0	57	0.5
28	5.0	58	0.6
29	3.6	59	0.5
30	4.2		—

Note.—These readings were taken before changes had been made in auditorium central unit.

DISCUSSION.

Mr. J. R. Cravath:—As to the question of the relative effectiveness of indirect as compared to direct lighting, I do not want to be quoted as saying or giving in any of my papers the impression that at the present time as far as our knowledge goes there is any particular difference in the amount of light required for reading under the two systems. The paper which I read

here at the convention indicated that there is very little difference, if any, under ordinary conditions. There was a theory held by some until recently that there is quite a difference in favor of direct lighting. Of course, this question of audience room lighting is one that is intimately connected with the bad effects of what we commonly call glare. Now, I think it is well to distinguish between the different effects of glare. I think we might divide the detrimental effects of glare and treat them under two rather distinct heads; one is the effect of reducing our ability to see clearly, sometimes called depression of visual function. That seems to be something akin to halation on the photographic plate. That is, if we look, for instance, at an object past one of these lamps here in the line of vision and we suddenly shade our eyes from the light we can see the object more clearly. This first effect I should call physiological, probably. Then there is the other effect which is psychological, and that is when we have a bright light anywhere within our field of vision; no matter how far it is away from the center of vision, the tendency is to give our attention to it. In other words, it is a distraction and annoyance. We may by will power or by effort, either consciously or unconsciously, be able to see the past thing and see as clearly as we could before, but it is with an effort. I think it is well to bear those distinctions in mind.

Mr. A. J. Sweet:—I don't know that I can add very much to the discussion Mr. Cravath has already put before you, but I should divide the question a little differently than he has divided it, into two entirely separate phenomena. One is the depression of visual function that Mr. Cravath has made very clear and the other is the question of discomfort. The other things are entirely independent at least for all practical purposes. If there is a relation between them it is something that does not appreciably affect the practical questions involved in design.

The question of discomfort is a question of intrinsic brilliancy. The presence of light giving objects or light reflecting objects of high intrinsic brilliancy though the total amount of light given by them may be small is extremely trying. It is just like the prick of a pin, it is extremely uncomfortable.

The depression of visual function is a question of the amount of light thrown into the eye at each angle in the line of vision. Of course, we all realize that light thrown into the eye directly along the line of vision reduces the greatest amount of halation effect that Mr. Cravath has spoken of, and within about twenty-five degrees of the line of vision the effect of the light on the depression of the function of vision ceases.

One important point, of course, in theatre illumination is to avoid the discomfort due to bright light sources. I believe those indirect installations that Mr. Vaughn has presented so ably before us are practically ideal in this particular. I don't believe that any direct installation could be made so comfortable as these that have been presented. The question of the effect of the depression of visual function, however, is something that requires further investigation. I should expect to find quite a large effect in decreasing visual function in types of illumination such as have been considered.

There are certain features that I believe could have been emphasized in this paper that I don't want to take your time to discuss but just to mention two or three of them. One of the noteworthy features of any indirect installation is the elimination of marked shadows. I believe that when that is done as intelligently as in the cases set forth in the paper that it greatly increases the attractiveness or personal appearance in gatherings under such installations. The presence of sharp shadows is very objectionable. An important feature in theatre lighting is to show up everybody in their most attractive style, and I believe that that advantage can be credited to this method of illumination.

Mr. O. J. Bushnell:—Mr. Vaughn referred to an installation of indirect lighting with translucent reflectors; I would like to ask him if he considers this type of fixture an improvement for this style of lighting over the opaque type of fixtures which are in general use to-day as evidenced by the illustrations he has shown; also if he considers the semi-indirect fixtures to be as well adapted to theatre illumination?

Mr. F. A. Vaughn:—I don't know that I have, as yet, formed any definite opinion on that point. It is an attractive form of

equipment for theatres it seems to me, and I would be very glad indeed to see it tried out and then form a judgment of it. It is possible with this type of unit to conceal the light sources from the direct vision, subdue the intrinsic brilliancy by the diffusing glassware and produce an effect which is akin to that produced by the indirect fixtures, overcoming the possible objection to the opaque fixtures by allowing some of the light to come through, with resultant various artistic effects produced by the light coming through. There are some attractive features about it, but as to whether it is an improvement over the totally indirect for this purpose, or not, I think perhaps it is too early to form an opinion.

Mr. T. H. Aldrich:—I would also like to ask what is the consensus of opinion of those who have attended plays at the Pabst Theatre since the new installation of indirect lighting was installed, as regards the effort to see the actors and stage, and also if one notices that there is less eye fatigue after the show is over, than if some of the direct lighting systems were in use?

Mr. F. A. Vaughn:—As intimated in the paper the installation has only just been completed, and we have had no opportunity since it was completed to actually make visual acuity tests, or fatigue tests, on subjects brought there for that purpose; but, of course, we have been very much interested in knowing how the audience and the management felt about it, and we have without exception received the highest praise for the effect in that theatre of the indirect illumination; that is, the pleasant effect, the lack of fatigue and the visual comfort that is produced by it. Simply from the vote of the people who have been there I would feel free to answer that the factor of fatigue is quite decidedly eliminated, while under the former installation it was very prominent. I can attest to that—the last part of the foregoing statement—because I have been there very many times to lectures, concerts and grand operas.

Mr. J. R. Cravath:—I would like to propose a modification of Mr. Sweet's suggestion that annoying glare is dependent upon intrinsic brilliancy. I think it is a question of intrinsic brilliancy as compared to the surroundings. In other words, it is not the absolute intrinsic brilliancy but the relative intrinsic bril-

liancy which determines the annoyances. We know very well that a lamp with a certain intrinsic brilliancy under very bright surroundings in daylight is hardly noticeable where under dark surroundings it might be very annoying. That is something that always must be borne in mind when we are talking about annoying glare.

Mr. F. A. Vaughn:—I do not want to take your time to say anything further except this: that we hope we have impressed all present with the breadth of the subject and the interesting points that there are waiting for solution by the illuminating engineer. We realize, as Mr. Sweet said, that there are many points that could be, and perhaps ought to have been, accentuated, but to do that, or to accentuate even a portion of those that deserved it, would have taken more time and space than we are entitled to, and we were hoping to bring some of them out in discussion. In preparing a paper of this kind and in doing work along the lines indicated it was soon evident that there was very little correlated information to be secured, and it was hoped that this paper would attract the attention of the illuminating engineers to this subject with the idea of getting something together on which practical illuminating engineers can base future work.

THE CONSERVATION OF VISION.[1]

BY ELLICE M. ALGER, M. D.

There is a growing tendency in modern times to consider the individual a mere unit in a great industrial organization. If he dies in childhood he has cost his parents and society a definite average sum which death has deprived him of the opportunity to repay. Every such death is a total loss. If he grows up his value is estimated in the same way. If he creates more than he consumes he is an asset; if he consumes more than he creates he is an actual liability, since society no longer allows him to perish miserably of neglect but collectively assumes the responsibility for his support and care. Society therefore has a direct interest in the health of each of its units, because ill health not only increases cost but lessens productivity.

Furthermore each individual has a maximum amount of work of which he is capable and to allow him to do less or to force him to do more is economic waste.

On the basis of these two ideas, health and efficiency, there is a widespread social agitation for such various objects as the eradication of preventable diseases like typhoid and tuberculosis, the lessening of alcoholism and insanity, the restriction of the labor of women and children, pure food, health insurance, and the like.

There are some eighty thousand people in the United States, who, through often unnecessary blindness, have become social liabilities instead of assets and it seems most appropriate that there should be a number of societies, state and national, devoted to the prevention of blindness. But from the economic standpoint this is a comparatively small matter.

In the United States there are several million people who are not blind nor likely to be blind, but who make their living chiefly by their eyes and who fail to realize anything like their full efficiency by reason of defects in their eyes or in the condi-

[1] A paper read before the New York section of the Illuminating Engineering Society, December 14, 1911.

tions under which they work. The suffering and the economic loss from inefficient eyes is beyond all calculation. To the conservation of vision in this wider sense the attention of the reader is invited.

The phrase "preventable blindness" inevitably brings to mind ophthalmia neonatorum, the infection of the eyes of the newly born child, of which so much recently has been heard. In past generations it was a veritable scourge, especially in the large maternity hospitals, in some of which it occurred in fifteen per cent. of the children born. With the methods of treatment then in vogue the results were appalling and it was estimated that every second blind person owed his misfortune to this cause. A little over a quarter century ago Credè taught the world that the instillation of a drop of nitrate of silver solution into the eyes at birth would practically abolish the disease. To-day, partly owing to the widespread use of the method he taught, and partly owing to the general improvement in midwifery, the disease has become comparatively a rare one and many physicians of large experience have never seen a case. It used to be believed that ophthalmia neonatorum could not occur except when the mother had been previously infected with a venereal disease, generally of course through her husband's infidelity or premarital indulgences. Unfortunately these ideas still prevail both among physicians and laymen, and are being sedulously cultivated by the societies formed for the restriction of venereal diseases, and for the establishment of the single standard of morals for men and women alike. Many physicians therefore take no precautions at all except in cases where they have reason to suspect the present or past virtue of one or both parents. To-day, however, it is known that ophthalmia can be caused by any one of half a dozen pus producing germs, and that in from one half to a third of the cases it is not due to any antecedent venereal infection at all. It is liable to occur in the most virtuous of families and, for this reason, the routine precautions should be taken even when both parents are above suspicion. So much publicity has been given to the other idea, however that the laity consider almost any kind of a sore eye in a young child as casting suspicion on parental virtue. The dangers of ophthalmia have doubtless been exagger-

ated, but the public agitation has done a lot of good. At present there is an organized national crusade to instruct mothers, remind physicians, and educate the ignorant and dirty midwives who in our large cities preside over more than half the births. It is reasonable to expect that soon ophthalmia neonatorum will be classed with hospital gangrene and other diseases which are to-day medical curiosities. Meantime, excepting foundlings and those who are either entirely neglected or over-treated, most of these babies come out with perfectly good eyes.

From the social standpoint trachoma is a much more important disease than ophthalmia neonatorum. When the soldiers of the great Napoleon found their way back to France after the disastrous Egyptian campaign they brought with them an inflammatory disease of the eyes which in later campaigns they spread all over Europe. Like most new infections its virulence was greatest in the beginning, and its contagion and its virulence were markedly increased by the universal poverty and hygienic ignorance of the time. There were epidemics of trachoma. One reads of outbreaks occurring on shipboard so severe that before the end of the voyage no sailor was capable of duty; of whole companies of soldiers incapacitated. The resulting amount of blindness and disability was appalling. In the Orient the disease is still so common that unscarred lids and clear corneas are said to be the exception rather than the rule, but among civilized peoples, as the standards of living and hygiene have improved, trachoma has become notably less infectious and the damage it does to the eyes is nothing like that of the last century. Nevertheless, though there are other diseases more violent and immediately dangerous, there is none which produces so acute a discomfort for so long a time; there is none which lasts so long, or is accompanied by so many relapses and exacerbations, there is none which has so many complications and sequelae, and none except those which result in absolute blindness that causes such permanent disability or is so stubborn to treatment. Trachoma was discovered in America almost as soon as it was found in Europe. It has long been prevalent among the French Canadians of the north and the poor whites in the river bottoms of the south, but for the most part the comparatively high standard of living in

this country has prevented its becoming a national scourge, till the last wave of immigration from Europe's lowest social strata in Russia and Italy. All the large cities in this country are full of trachoma in spite of the fact that to-day every immigrant who presents even a suspicion of the disease is turned back.

In spite of a century's experience comparatively little is known about it. Under certain conditions it is known to be extremely contagious; but, so far, its cause has eluded discovery. There are a number of remedies and methods of treatment which ameliorate the symptoms but it is admitted that the resulting incapacity depends far more on the virulence or mildness of the infection than on any particular skill or lack of skill in the treatment.

Unfortunately, while there is no difficulty at all in recognizing the disease in its latest stages, it is very easily confused with other affections in the beginning. The word trachoma means a rough or granular lid and it was natural to assume that every granular lid was trachomatous, which is very far from being the case. Some years ago it was discovered that fully twenty per cent. of the children in our public schools had granulated lids and it was at once assumed that this was identical with the trachoma of immigrants. Thousands of children have lost countless hours from school in having treated eyes as nearly normal as those of most of this audience to-night. Thousands more with more marked granulations have been operated upon, some of them every year for several years, for a condition which most authorities to-day are agreed is not true trachoma; is not certainly contagious, gets well almost of itself in time, and occasions practically no discomfort or disability in the process. True trachoma is comparatively rare among school children, while among adults the increasing use of soap and water and the diminishing vogue of the roller towel are rapidly solving the problem of its communicability.

But the campaign against ophthalmia and trachoma has only scratched the surface of preventable blindness. For every one of the totally blind from these diseases, there are ten practically blind from other more or less preventable causes of which society to-day takes absolutely no notice. Many of the common diseases of

childhood, notably measles, are attended or followed by inflammation of the eyes. The same may be said of tuberculosis, syphilis and many other forms of malnutrition and disease. Such conditions, even if treated properly and promptly, frequently damage beyond repair one or both eyes; while, if negected, they are extremely dangerous.

Through parental ignorance, or neglect, or physical inability, many children are not seen till too late; others cease treatment before they are well; others get no care at home from that excessive love which cannot bear to carry out any treatment which causes pain. From all these causes there is a host of children who, though they seldom lose an eye entirely, have permanent scars that cannot be removed and which make the eye a more or less imperfect visual organ.

Such children are thought stupid, when as a matter of fact, they are half blind. Each scar has the same effect as a flaw in a window pane. One so small as to be hardly noticeable may reduce the vision fifty per cent., while there are numerous children with half a dozen, large and small, scattered over both eyes, hopelessly incapacitated for life from any calling which requires fair sight. They cannot learn readily in school, are neglected or bullied by their teachers, miss promotion after promotion, and finally, without education or trade, are condemned for life to the coarsest kinds of manual labor.

Society must sooner or later adopt some measures for the prevention and the treatment, compulsory if necessary, of these conditions.

Then there is also the relatively uncommon, but in the aggregate very numerous, list of lost or impaired eyes from preventable accidents at play or at work. These seem pure accidents which can neither be foreseen nor prevented; but most of them occur with a regularity which compels a different conclusion. Every clinic in New York, for instance, sees in the course of a year a number of cases where a young child, in trying to disentangle the knot in a shoe string with the sharp point of an ice pick or scissors, has punctured and ruined an eye. Similar accidents occur from the foolish habit of holding a loaf of bread with one hand and slicing toward the body or the face with

the other. There is a regular average number of eyes lost every year through such a common cause as being hit by the popping cork in opening bottles of soda water. A western surgeon recently was able to collect a long series of cases in which an eye was ruined by having the firing pin or breach block of a defective rifle or shot gun blown back into the marksman's eye. There is also a regular crop of ruined eyes after every Fourth of July celebration.

Anyone who pays the slightest attention to the various ball and missile games of children, their air-guns and their bows and arrows, can only wonder that accidents to the eyes are as relatively uncommon as they are.

Among workmen the daily total of more or less dangerous accidents to the eyes is something enormous. Consider the men employed in the various grinding trades for instance. In working over an emery wheel there is a constant stream of small particles thrown off at great speed from the wheel itself or from the tool or casting. Various safeguards have been devised to protect the eyes, some of which are expensive for the manufacturer to install, and others inconvenient to the man at his work; and they are seldom used.

The experienced man has learned to work in such way as to save his eyes as much as possible, but the beginner is always in trouble. When these particles are small they are removed by fellow workmen with the corner of a soiled handkerchief, the soft end of a chewed tooth pick, or the point of a dirty pen-knife. Many are more deeply embedded, even if they have not gone clear through into the eyeball itself. Many injuries, trivial in themselves, are infected by dirty shop manipulation, causing suffering, loss of time, more or less disability and often loss of the eye itself. Every one of these emery particles except the most superficial, produces a minute but permanent opacity in the cornea, which, if rightly situated, interferes seriously with sight. The author has seen men who showed a dozen or more scars in each eye as the result of repeated injuries of this kind.

Then, too, there are the less common but much more serious injuries due to defective tools. For instance, in hand drilling a sort of fringe of metal develops at the top of the drill from the impact of the sledge, till finally a blow not exactly square

breaks off some of these pieces which fly into space with tremendous velocity and very commonly pass clear through an eye. A large number of similar accidents occur throughout the country from the sale of cheap tools, such as hammers, and hatchets, which have been cast instead of forged. In driving a heavy nail, a glancing blow has many times broken a large chip from the head of a hammer, which has penetrated an eye. Some of the most brilliant operations of ophthalmology are made possible where these foreign bodies are magnetic metals and can be extracted by the use of a giant magnet, but one is frequently allowed to lose sight of the fact that whether the operation be successful or not the eye is very seldom of any great use for visual purposes.

When the foreign body cannot be removed by the magnet, as for instance a bit of brass or stone, the eye is almost invariably lost with additional and very real danger of sympathetic inflammation of its fellow unless the injured eye is removed. This danger of sympathetic inflammation hangs over the workman like the sword of Damocles, if he did but know it, instances of its development twenty years after the original injury being on record. But it is hard to make him realize that an eye which has quieted down can possibly be a source of any danger.

There are many other trades, each of which has its own peculiar accidents to the eyes, like the lime burns of the plasterer and the mason, and the solder burn of the plumber and the tinsmith. There are also many trades in which, though free from accident, the workman loses his sight through trade poisoning of one sort or another, and the number of these is constantly increasing as our manufacturing processes become more complicated.

It has been known for generations that in some individuals the excessive use of alcohol and tobacco, separately but more often together, produces an amblyopia or blindness. The oculist has to keep this fact constantly before him in the examination of many people who are at first sight neither drinkers nor smokers. In may affect alike the ignorant worker in a badly ventilated cigar factory or the cutivated lady who inhales her cigarettes.

Fortunately if its cause is discovered it is generally very amenable to treatment.

But there is a new and much more serious danger to which the people of this country particularly are all more or less exposed. Owing to the high revenue duty on grain alcohol, it has become extremely profitable to manufacture methyl or wood alcohol, which though actually costing more to make, can be sold much cheaper than the grain variety and has displaced it in many of the arts. It was not intended for internal use at all but has been consumed by the ignorant and benighted as furnishing a cheap and very potent source of intoxication. Such sprees often end in death and more often in a specific type of blindness. Since attention has been directed to this subject, it has been found that in susceptible individuals a very small dose of wood alcohol will produce total and permanent blindness. To this cause may be traced a good many cases which were before mysterious. For instance, a little German tailor started for work one morning, and not feeling very fit, stopped at a cheap saloon on the way and took one single drink of spirit. Before noon, he had to leave work and the next day, when the writer saw him, he could barely discern the presence of a hand waved in front of his face. He became totally blind from that one drink. A sort of epidemic of blindness and death on the west side of New York was traced to the parsimony of an ignorant saloon keeper who manufactured his drinks with wood alcohol because it was cheap. Neither is this a danger for the poor alone, for wood alcohol was formerly used in extracts, essences and patent medicines, by manufacturers who were either ignorant of the dangers, or thought it harmless in small doses. But ten drops has produced blindness in an individual who took it experimentally in a spirit of bravado. Furthermore instances are accumulating where the same results have followed its use as a substitute for grain alcohol in bathing and rubbing, probably by inhalation of the vapor. But even to-day some druggists sell it for external use and many physicians are unaware of its danger when so used. Only recently in this city a saloon keeper, convicted of adulterating his drinks with wood alcohol was let off with a small fine by the court, while a man convicted of

stealing milk from the porch of a prominent politician, went to the island.

Apparently there is no legitimate excuse for the manufacture of wood alcohol, especially since denatured grain alcohol for use in the arts can now be obtained tax free. But there is a good deal of capital engaged in its manufacture.

There are many other dangers to sight which confront those employed in various trades, and this list is rapidly extending. Workers in lead, arsenic and rubber become poisoned and lose their sight. Even medicines are not always the innocuous things they seem. Blindness has often followed the injudicious use of such common drugs as quinine and salicylate of soda, while we are just beginning to realize the dangers of some of the new arsenical compounds, which are now so fashionable. A long list of cases of permanent blindness from their use has gradually accumulated in medical literature.

The disabilities from all the aforementioned causes, from accident, from disease, from occupation, not only cause suffering to the individuals involved, but they impose in the aggregate an enormous economic burden on the community in which they happen. But they are after all, from the economic standpoint, but a mere drop in the bucket as compared with the loss to the community through the multitudes of people who fail to realize anything like their full efficiency because of the functional eye defects which are called errors of refraction.

It has been often said that the human eye is but an expanded portion of the brain, but one seldom stops to think how complicated a function vision really is. Not only must the retina of each eye be exquisitely sensitive to light, but the refractive media must be capable of instantaneous adjustment; so that a clear image may be formed on that retina, whether its object be far or near. Furthermore that perfect image must be formed on one particular spot in each retina, and the brain behind must combine the two sensations in order to form the visual judgments which are called seeing. Distinct single vision requires a complete coordination of the two eyes, which is accomplished by the joint action of fourteen separate muscles. So necessary is the function of vision that four of the twelve great cranial nerves are devoted to

it exclusively, and it is so complicated that the slightest abnormality of nerve or muscle either throws the entire visual machinery out of gear, or makes the task of coordination more difficult. When one stops to think that most people use their eyes almost constantly and that many tasks involve a continuous strain for hours at a time, one begins to understand why vision necessitates expenditures of nerve and muscle energy beyond any other function. And when one further considers the large area of brain devoted to vision, and the very close relationship anatomically between the visual centers and other centers, it need not seem strange that what is rather loosely termed eyestrain may exercise a profound and varied influence on those other functions.

A patient is said to suffer from eyestrain when his eyes are compelled to do work which is beyond their physiological capacity. Unfortunately there are no exact standards for measuring this capacity; there is only a standard of averages. It is known, for instance, that the average patient can read letters of a given size at a given distance; but there are many whose acuteness of vision is far beyond the average. In the same way, there is an average ability to focus near objects which is greatest in youth and diminishes regularly with age, but this power varies enormously even in individuals of the same age.

But to measure the equally important element of endurance is still more difficult. Just as the strongest man is seldom the most enduring, so the optically perfect eye may be absolutely incapable of enduring continuous hard work.

It is a great though often forgotten physiological law that any organ exercised well within its limits tends to increase in power and facility, while if overworked it becomes less and less able to do any work at all. If a man habitually uses his eyes in strong lights he decomposes his visual purple faster than it can be regenerated. If he uses his ciliary muscles without rest day after day they begin to break down under the strain and become fatigued even by very short periods of use.

It is therefore perfectly possible to strain even normal healthy eyes by overuse, especially under unfavorable conditions and in lowered health, but the chief strain comes from the efforts of

the abnormal eye to compensate for its own optical defects. The normal eye sees distant objects distinctly without any necessity of focusing and has to accommodate only for close work. But the eye which is far-sighted or astigmatic has to accommodate even for distant objects and has correspondingly less power available for close work. But accommodation is a muscular effort, just as much as running or lifting, and produces a normal fatigue. The individual who by reason of a refractive error has to accommodate too much must accordingly become tired sooner than he otherwise would.

Within the narrow limits of a paper like the present one it is not possible to more than allude to the multitude of symptoms which may result, in susceptible individuals, from eyestrain. They are of more interest to the physician than to the layman, since they include, in addition to disturbances of vision, the majority of chronic headaches, many functional disturbances of distant organs, and many conditions of nervous and muscular exhaustion. To the layman the social and economic sides of the question are far more interesting.

Most people have their work so arranged that it is not necessary for them to realize their full efficiency and when they are tired they rest or change their work, but among people who have to earn their living by the continuous use of their eyes for close work these errors of refraction are a tremendous handicap. A prominent lawyer once told the present author that for years he had lost at least one day a week from his office by reason of the sick headaches caused by his astigmatism. It was easy to estimate the cost of his astigmatism to him. But if he had worked for some one else instead of for himself he could probably not have kept his position at all.

These refractive errors are practically all congenital defects of development. The far-sighted eye, for instance, is too short; the myopic or near-sighted too long, and the astigmatic more or less egg-shaped instead of round. But while in the well-to-do classes these errors are common enough, they are often slight and easily compensated for. But among the tenement-house population, badly housed, ill fed for generations, diseased, these developmental errors are not only practically universal but often

so great that they cannot be compensated for by any amount of strain. Many of the occupations of the poor, too, compel a continuous close use of the eyes, far beyond that of the lawyer in the case just cited. Among the east side operatives, for instance, thousands and thousands of men and women spend their lives making the fractional part of a coat or a shirt waist; and workers in artificial flowers and willow plumes labor under similarly trying conditions. They all suffer from errors of refraction, large or small. They all have less than the normal compensatory power because their muscles are overworked and badly fed. They work in close, badly ventilated, badly lighted work rooms, driven to the utmost by the piece system and the uncertainty of work. After a few hours their eyes get tired, but they cannot stop or change their work. Presently the daily headache begins and, a little later, the tired attention begins to flag; they begin to make mistakes in their work and for every mistake there is a regular tariff of fines and deductions. Some of them cannot hold any place long, they spoil so much work. Others are fined so much for mistakes that their weekly wage is a mere pittance, not enough by itself to support life. Not only is their financial position a pitiable one, it is practically a hopeless one. They know how to do nothing else. They often know no English, they have no friends, their acquaintances are all competitors. Each night sees them utterly fagged out with no appetite for normal amusement and each morning sees them back at the same old treadmill. They all have headaches, which they consider for the most part a regular inevitable part of the life they lead. Life for them is one continuous round of depressing monotonous labor, poorly paid and without future. Many of them are regular consumers of headache powders. Here may be cited the case of a young Jew who came under the writer's observation. His skin was a ghastly indigo blue in color. Investigation proved that for over two years he had consumed daily more than a box of headache tablets, so that he could do his day's work and his blue color was due to the resultant deterioration of his blood. The men take naturally to alcohol which braces them up for the day, benumbs their headaches, and makes them forget their sorrows. The girls

are in a state of constant hopelessness and misery, the only avenue of assistance or escape being a man—or men.

The moral and spiritual results of inefficient eyes are seldom thought about; but they nevertheless exist. They account for the backward school children, who learn badly or not at all, who have the reputation of being stupid and obstinate; qualities which all disappear under the stimulus of a little sympathy and care. When they cannot earn a living in legitimate ways in later life, many of them earn it by their wits at the expense of society. It has been proved over and over again that the inmates of institutions and reformatories present a tremendous number who are not half so defective mentally and morally as they are visually. The combination of physical misery and low wages imposed by bad eyes, undoubtedly predisposes the man to alcoholism, dishonesty and crime and makes a life of prostitution seem easy and attractive to the girls.

This situation is a tremendous social tragedy, both from the individual and the community point of view, and all the worse because most of it is entirely unnecessary. There are, of course, many people who under the best of conditions cannot earn their living with their eyes, just as there are lots of perfectly healthy men who could not make a success as longshoremen, but the great majority of these people with proper glasses can do their work with only normal fatigue and do it with great increase in both quality and quantity. When evening comes they have vitality enough left to learn or enjoy, and their perspective on life itself is more nearly normal. But the majority of them do not know even what their trouble is. They often think that they can see perfectly well and suppose that they have as good eyes as anybody in the world. Many of them are sure that their troubles come from other causes (as, of course, they sometimes do) and take medicine year in and year out for supposed disorders of the stomach, intestines or nervous systems.

One cannot fail to be impressed by the fact that the average person whether layman or physician has only the haziest idea as to what constitutes proper care and use of his eyes.

People must be taught not only the amount of work they can

do without overstrain, but the intervals at which a short rest will increase their real efficiency. They must learn something, too, about the conditions under which they can work to best advantage. Proper artificial lighting, for instance, is signally important. The general impression seems to be that that room is best lighted which is most lighted, and that lighting like banking should be centralized as much as possible. This is a great mistake. Too intense a light decomposes the visual purple in the retina faster than it can be replaced and leaves a condition of retinal exhaustion. Likewise it compels a constant extreme muscular contraction of the pupil in the effort to exclude the light, which is both fatiguing and painful. Most of our buildings, both public and private, are glaring examples of extravagant and inefficient lighting, extravagant because of the waste of light, and inefficient because they are not comfortable even to sit in. The problem of lighting the factory or the school room where the eyes are to be used for continuous close work is still more complicated. Not only is the amount of light to be carefully considered, but it must be correctly arranged. It is easy enough to arrange the details so that one workman or student shall have sufficient light without any of it either shining directly into his eyes or being reflected into them, but every additional worker makes the problem more difficult. With the many modern methods of commercial lighting by gas and electricity the composition of light as well as its intensity has become important. In the days of our forefathers with their candle-light and student lamps the problem was simply one of quantity, the quality being suitably soft and pleasant. But our modern lights whether gas or electric are often so intense as to be extremely fatiguing. They also contain many more of the violet and ultra-violet rays of the spectrum which are useful to us in the so-called light therapy and in radiography but are certainly unsuitable for illuminating purposes. There seems to be no question that lights which are, in sufficient volume, capable of tanning and sunburning the skin may be responsible for a large part of the asthenopia which is so prevalent to-day. Furthermore their effects on the deeper structures of the eye are suspected of being still more serious. The refractive media of the eyes undoubtedly absorb most, if not all the

ultra-violet rays, so that the retina suffers little harm; but it is quite possible that this continued process of absorption may result in those little understood changes in the lens which are called cateract. It is a certainty that stokers, glassblowers, and the like, who are continually exposed to very intense light and heat have an enormously increased liability to cateract.

There seems to be no question that illumination made up chiefly of the red and yellow rays of the spectrum is the best for visual purposes and the problem of securing a light which shall allow the maximum of efficiency and comfort and convenience is one for the illuminating engineer rather than the physician. But it cannot be too strongly emphasized that this is no mere academic question but that its solution means not only comfort but dollars and cents to every one who works by artificial light or has others working for him.

People must be made to realize that eyes are not mere optical adjuncts, but integral parts of the body; that the eyes affect the functioning of other organs and are in turn affected by them; that insufficient eyes are the cause of the great majority of chronic headaches, of some indigestion, of many conditions of depression and fatigue. But these conditions are merely symptoms which may proceed as well from numerous bodily diseases. In other words that examination of the eyes is as much a part of medicine as examination of the heart and lungs. People must be taught that the fitting of glasses, if it is to be done thoroughly and properly, is likewise a medical matter and that for people who have to make their living by the use of their eyes regular periodical examinations may vastly increase their efficiency and comfort. There are in my judgment few greater social needs to-day than the development of some system by which the great mass of the people can get a good eye service at prices they can afford.

Our forefathers, when they approached the age of fifty, and felt that the inevitable would no longer be postponed, went to a jewelry shop and selected their own glasses, partly because in many cases of simple old sight this was a very satisfactory method, but chiefly because there was no other way. A little later a few physicians took up the specialty of ophthalmology,

and in the intervals between operating and treating diseased eyes they did a good deal of refraction work. Examinations by men whose time was in such constant demand was expensive, and the great majority of patients felt that they personally neither required such expert help nor could afford such fees except in cases of absolute necessity. More and more they asked the advice of the optician who ground the glasses and who was glad to give gratuitous advice.

The situation is not so very different to-day. There is a small class of expert oculists whose fees are large and a larger class of pseudo-experts charging expert fees; but the great mass of the people, whether from inclination or necessity, still consider the jeweller or the optician their adviser. The optician, however, is not a professional man. He is primarily a salesman of optical goods, whose success is made in direct proportion to his knowledge of human nature. Beyond that he often has only the most rudimentary knowledge of his business. Furthermore, the margin of profit is so enormous and the opportunity for fraud has rendered the field so attractive to the unscrupulous, that the opticians themselves in many states, including New York, have recognized the necessity of having laws passed setting standards of character and knowledge.

But the licensing of the refracting optician was not an unmixed evil. Whether good or bad, the medical profession was certainly responsible for it in the sense that it was not prepared then, any more than it is to-day, to afford a good eye service except to the well-to-do. Laws of some kind were certainly necessary to protect not only the ignorant poor, but the ignorant rich. Unfortunately such laws protect the public only secondarily. Our present laws prescribing examining boards will in the course of a generation or two, so raise the standard that a state license will have a real, if limited, value; but for the present at least, it generally means no more than that the holder has been able to find reputable citizens willing to swear that he has a good moral character and was actually engaged in the business of selling glasses at the time the law was passed. The law was purposely constructed to exempt him from tests of any kind.

There are doubtless exceptions, but for the most part the optician has had no training in the physiology or pathology of the eye, to say nothing of those of the human being behind the eye. He often has only the most rudimentary knowledge of the optical part. There are many eyes which cannot be measured successfully without the use of drugs, which the law especially forbids him to employ, and the glasses he dispenses very often aggravate the conditions they were intended to relieve. Naturally too, he generally overlooks all but the most glaring organic diseases of the eye itself, as well as the indications in the eye of organic diseases of other parts of the body. More than that, he has more than once been known to advise patients with serious ocular diseases not to consult a physician.

The vogue of the refracting optician, like that of the vender of patent medicines, depends chiefly on a complete ignorance, both lay and medical, of the intrinsic value of the goods he sells. The old time optician ground his own lenses. His modern successor may have his factory on the premises but he buys his lenses from the wholesaler, at a few cents apiece, and all the grinding he does is that necessary to mount them in their frames. Often he could no more make a pair of glasses than the seller of ready made clothing could make a suit of clothes. But the patient who is persuaded that gold is more becoming than steel, and solid gold a better investment than filled, and that the optician has invented the only really scientific clip, is yielding a clear profit of several hundred per cent. Rich and poor alike often pay more for the simplest kind of glasses than the average oculist's fee and the glasses together should cost.

The cure for this sort of thing is education. The public is already beginning to realize that glasses like most machine made products are really very inexpensive and that their apparent cost is in effect an examination fee. Competition is already at work. Some opticians are selling glasses on a business basis and refuse to examine eyes because, at the prices they charge, it does not pay. Others are beginning to charge a fee for the examination, just as a physician would do, and not infrequently try to give customers the impression that they are physicians by virtue of their "Doctor of Optometry."

But one thing is certain. The general public must have eventually a service which it can afford and which it can trust, and one of two things must happen. Either the general practitioner must take up simple refraction or some means of educating the younger generation of refracting opticians by a semi-medical training, like that of the modern dentist, must be devised.

The question of the charitable treatment of the indigent and the improvident, or of the hordes of children in our public schools whose examination is an admitted public necessity to-day can only be alluded to in this paper. The medical profession which has for generations carried this burden of medical charity, not always without complaint, is certainly growing restive under a social system which causes a constant increase in its gratuitous work and as steady a diminution in its average income. The physician is always ready to respond to the call of suffering, but it is an open question how far it is his duty to give, gratuitously, services which are intended solely to increase efficiency or earning capacity. Particularly is this true of the children in our public schools. It is neither right nor for the best interest of the children themselves that a small class of specialists should be saddled with the entire burden of their gratuitous treatment.

Our system of school inspection was established with the idea of detecting in their beginning the various contagious diseases of children, before they have a chance to spread. Naturally enough this was the function of the health department, which selected for its inspectors young physicians, who were familiar with diphtheria, scarlet fever and the like. Later on they began to pay attention to many other forms of disease with which they were not by any means so familiar. Then, too, the actual inspection work has more and more fallen into the hands of the school nurse and the number of physicians is being steadily reduced. When the nurse finds some abnormality about the skin, or the eyes, or the throat, instead of being able to pass upon it herself with some certainty, she refers the child to the family physician or more often to some neighboring dispensary. All our dispensaries are swamped with children from four years upward, who

come generally without their parents, and for the most part without any definite idea of why they do come. A multitude of these children lose time from school for troubles of the most trivial sort, and a multitude more have more or less serious trouble with so many different organs that they could easily spend their entire day going from one department of a dispensary to another. They must see a different physician for their eyes, their teeth, their throats, their glands, to say nothing of their more vital organs. Each department looks after a fraction of a child, and no one knows what the rest are doing, whether the child improves or get worse, whether it gets any care at home, or even uses the medicines that are provided. The whole idea is wrong. What is really needed is a system of inspection whose justification shall be not the number of children excluded from school, but the number kept in.

Whether education be considered as a preparation for life or as an end in itself it must first of all be suited to the physical and mental capacity of the child. There are some children with eyes so hopelessly bad that to educate them like other children is not only a hardship to teacher and child, but an absolute waste of public funds. There are others whose eyes are likely to be seriously damaged by the very process of education. There are many others who, with appropriate treatment of their eyes, become for the first time capable of doing justice to themselves or their teachers. The same reasoning applies to other organs. Every child in a public school should be examined thoroughly, on entrance, by some one not only competent to discover ordinary defects, but responsible, so far as possible, for their correction. And the physical record of that child should go with him from grade to grade just as does the record of his scholarship. It seems ridiculous that there should be a staff of men and women who devote their entire time to what might be termed the gymnastic education and physical development of the child, while the functions on which scholastic success or failure chiefly depend are referred to outsiders who have only too often neither responsibility nor skill nor interest. There is a crying need for men and women capable of examining school children and there are, at present,

few to supply the demand. Perhaps no other medical work requires more skill, tact and common sense. It is a specialty in itself, combining portions of several of the ordinary specialties, and will require a special training. It is work worthy to be chosen as a life work and not a mere pot boiler till something better turns up. It will not be properly done till every school numbers among its teachers a physician trained and paid to do this work and not allowed to do anything else.

For a long time there have been institutions both public and private for the care of the blind. More recently institutions like the New York Association for the Blind, which promises to be the parent of many state associations, has begun perhaps the first intelligent effort to put the blind in the way of caring for themselves and securing "light through work." The American Medical Association and the Russel Sage Foundation have recently begun a tentative effort through public education at the prevention of blindness. But they all seek to impress people with the tremendous cost of blindness to the community in the way of money spent while, from the social standpoint, it is a mere drop in the bucket as compared with its cost in wages not earned and possibilities not realized. A campaign of education is needed, as much among the rich as the poor, to make them intelligent on the subject of their eyes, like those which are being effectively conducted on such subjects as tuberculosis and infant feeding. For this purpose there has recently been organized a great national Association for the Conservation of Vision, whose membership is not limited to physicians, but is open to all who are interested in furthering the objects of the society. It will take up in detail many of the topics which are merely touched upon in this paper and make a concerted effort in behalf of society at large, not only toward the prevention of blindness and the proper treatment of disease, but to teach people to secure for themselves the maximum safe efficiency of their eyes.

DISCUSSION.

Dr. Alger's excellent paper was discussed by a number of prominent physicians, among whom were Drs. M. [illegible], A. Lambert, F. Valk and John Richards. Written discussion was received from Dr. F. Park Lewis. Most of the points

raised in the discussion dealt with the medical phases of conservation of vision, although some of the important illuminating engineering aspects of the problem were adduced. Miss Caroline Van Blarcom, secretary of the committee on the prevention of blindness, of the Sage Foundation, spoke of the work of several philanthropic societies in an effort to conserve human vision. In citing conservation of vision as problem possessed of certain scientific interest mutual to the medical profession and the illuminating engineer, Dr. A. H. Elliott said that "the oculist and the optician, to some extent, have been working in their special lines of investigation the diseases of the eye, its physiological structure, and the correction of its physical imperfection. The illuminating engineers on the other side, have been dealing almost entirely with the physical properties of light, with light as a mechanical agent, electrical and mechanical efficiencies, etc. The illuminating engineer usually knew very little about the structure and the action of the eye, with perhaps a few exceptions; and I think the exceptions were just as rare of opthalmologists that had any very comprehensive notion of what illuminating engineering meant, or what constituted good and sufficient light."

NOTICE.

An index for the TRANSACTIONS published during the year 1911, volume VI, will be mailed with the January, 1912, issue.